A FRAMEWORK FOR UTILISING LEAN CONSTRUCTION STRATEGIES TO PROMOTE SAFETY ON CONSTRUCTION SITES

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This work or any part thereof has not been previously presented in any form to the University or to any other body for the purposes of assessment, publication or any other purpose. Except for any express acknowledgement, references and/or bibliographies cited in the work, I confirm that the intellectual content of the work is the result of my efforts and no other person.

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Abstract

The poor safety situation in the United Kingdom (UK) construction industry and its adverse socio-economic record are well documented in the existing literature. The application of Lean Construction techniques has been proposed as an effective strategy to address accidents on construction sites, a major safety concern in the construction industry. However, examination of the relationship between Lean Construction techniques and safety issues has been marginal. This study explores this relationship with the aim of developing a framework for using Lean Construction techniques to promote safety on UK construction sites.

A framework was initially devised based on a synthesis of the literature and further refined based on findings from interviews held with 10 Lean Construction practitioners on antecedents of Lean Construction techniques and safety issues. In order to develop and confirm the framework, data was collected from practicing Lean Construction organisations using a questionnaire survey and analysed using descriptive statistics, inferential statistics and inter-rater agreement statistical test to examine the pattern and extent of the relationships.

The study found a total of thirty-eight (38) relationships between Lean Construction techniques and safety issues. These relationships are mainly positive in nature in that they demonstrate path to improvement in safety on construction sites. They show which techniques could be used to address the relevant safety issue. Furthermore, it was established that the application of Lean Construction techniques on construction sites can be impeded by challenges such as: lack of Lean Construction knowledge, complexity, misconception about Lean and difficulties in changing employees' working culture. The study identified strategies that could be used to address these challenges. These include enlightenment on benefits of Lean practice, publication of improvements realised from Lean practice, training, workers' involvement and empowerment, persistence, robust planning and gradual step-by-step implementation.

The study, therefore, concludes that Lean Construction techniques have positive relationships with safety issues on construction sites in the UK and on the basis of the relationships develops an integrated framework to guide application of the techniques by contracting organisations in promoting safety. The study makes a number of recommendations including the incorporation of Lean Construction practice into government health and safety initiatives, regulations and policies, and identifies areas for further research.

Table of Contents

Abstract i
Table of Contents ii
Acknowledgement xii
Dedication xiii
CHAPTER 1: INTRODUCTION 1
1.0 Introduction 1
1.1 Background 1
1.2 Aims and Objectives of the Research 3
1.3 Scope of the Research 4
1.4 Research Methodology 4
1.4 Research Assumptions and Limitations 6
1.5 Contribution to Knowledge 7
1.6 Dissemination of the Findings 7
1.7 Structure of the Thesis 8
CHAPTER 2: HEALTH AND SAFETY IN THE UK CONSTRUCTION INDUSTRY 9
2.0 Introduction 9
2.1 Health and Safety Records of the UK Construction Industry 9
2.2 Legislative Framework 11
2.2.1 Health and Safety Regulations 12
2.2.2 Health and Safety Executive (HSE) 13
2.3 Accidents on Construction Sites 15
2.4 Accident Causation Models 16
2.5 Causes of Accident in the Construction Industry 17
2.6 Onsite and Offsite Causes of Accidents 19
2.7 Lean Construction as a Strategy for Reducing Onsite Causes of Accidents 21
2.8 Summary 21
CHAPTER 3: THE APPLICATION OF LEAN THINKING IN THE CONSTRUCTION SECTOR AND ITS SAFETY IMPACTS 23
3.0 Introduction 23
3.1 The Concept of Lean Thinking 23
3.2 Application of Lean Thinking in Non-Automotive Sectors 25
3.3 Lean Construction 27
3.4 Lean Construction Principles 27
3.4.1 Value Identification 28
3.4.2 Value Stream Map 28
3.4.3 Flows 29

3.4.4 Pull 30
3.4.5 Perfection 30
3.4.6 Process Transparency 30
3.4.7 Benchmarking 31
3.4.8 Cycle time reduction 31
3.4.9 Flexibility 32
3.4.10 Balance Flow Improvement with Continuous Improvement 32
3.4.11 Process Simplification 32
3.4.12 Minimise Variability 33
3.4.13 Focus on Complete Process 33
3.4.14 Build Continuous Improvement into the Process 34
3.5 Lean Construction Tools and Techniques 34
3.5.1 Last Planner System 35
3.5.2 Increased Visualisation 37
3.5.3 The 5S (House-keeping) 38
3.5.4 Error-Proofing (Poka-yoke) 40
3.5.5 The 5 Whys 40
3.5.6 Daily Huddle Meetings (DHM) 41
3.5.7 First Run Studies 41
3.6 Lean Construction Practice in the United Kingdom 42
3.7 Challenges facing Lean Construction Practice 42
3.7.1 Management- related Issues 43
3.7.2 Financial Issues 43
3.7.3 Educational Issues 44
3.7.4 Governmental- related Issues 44
3.7.5 Technical Issues 45
3.7.6 Human Attitudinal Issues 45
3.8 Integrating Lean Construction Practice and Safety 45
3.8.1 Last Planner System (LPS): 46
3.8.2 Increased Visualisation 48
3.8.3 The 5S (House-keeping) 49
3.8.4 Error-Proofing 50
3.8.5 Daily Huddle Meetings (DHM) 51
3.8.6 The 5 Whys 52
3.8.7 First Run Studies (FRS) 52
3.9 Development of a Conceptual Framework 58
3.9.1 Input 58

3.9.2 Processes 58
3.9.3 Challenges 59
3.9.4 Strategies for addressing the Challenges 59
3.9.5 Negative Impacts 61
3.9.6 Strategies for addressing the Negative Impacts 61
3.9.7 Outcome 61
3.10 Summary 61
Chapter 4: Research Methodology 63
4.0 Introduction 63
4.1 Research Approach 63
4.1.1 The Quantitative Research Approach 65
4.1.2 Qualitative Research Approach 66
4.1.3 The Mixed Methods Approach 67
4.2 Choice of Research Approach 68
4.2.1 The Research Problem: 68
4.2.2 Personal Experience of the Researcher: 69
4.2.3 Audience: 69
4.2.4 Epistemological and Ontological Stance of the Research 70
4.3 Research Strategy 71
4.4 Data Collection Methods 73
4.4.1 Qualitative Data Collection Methods: 73
4.4.2 Quantitative Data Collection Method 74
4.5 Ethical Considerations 75
4.6 Sampling Techniques 76
4.6.1 Probability Sample: 76
4.6.2 Non-probability Sampling 77
4.7 The Qualitative Study 78
4.7.1 Sampling Technique Adopted 78
4.7.2 The Interview Design 79
4.7.3 Data Analysis Method Adopted- Thematic Analysis 80
4.7.4 Reliability and Validity Checks 82
4.8 The Quantitative Study 83
4.8.1 Sampling Technique 83
4.8.2 The Questionnaire Design 83
4.8.3 The Pilot Survey 84
4.8.4 Quantitative Data Analysis 87
4.9 Summary 93

Chapter 5: The Relevance of Lean Construction Techniques in Promoting Safety: Findings from the Qualitative Study 94
5.0 Introduction 94
5.1 Data Analysis 94
5.2 The Interviewees'/Organisations' Profile 95
5.2.1 Organisation Operations Area 95
5.2.2 Working Experience 96
5.2.3 Understanding of Lean Construction and its Application in Improving Safety 97
5.2.4 Relevance of Interviewee to Safety in the organisation 97
5.3 Lean Construction Tools applied in the Organisations 98
5.4 The Drivers for applying Lean Construction in the Organisations 100
5.5 Safety Impacts of Lean Construction Tools 102
5.6 Safety Outcomes of Lean Construction Practice 104
5.7 Outcomes of Lean Construction Practice in the Organisations 105
5.7.1 Positive Outcomes of Lean Construction Practice in the Organisations 105
5.7.2 Negative Outcomes of Lean Construction Practice in the Organisations 107
5.8 The Challenges encountered in Lean Construction practice 107
5.8.1 Changing Employees' Working Culture 108
5.8.2 Lack of Long Term Forecast and Investment 108
5.8.3 Long Implementation Time 109
5.8.4 Cost of Implementation 109
5.8.5 Misconceptions about Lean Construction 109
5.8.6 High Expectations from Management 109
5.8.7 Lack of Lean knowledge 110
5.8.8 Complexity 110
5.8.9 Lack of Cooperation from Employees 110
5.8.10 Lack of Incentives 111
5.9 Strategies that could be used to Overcome the Challenges 113
5.9.1 Enlightenment on Benefits of Lean Construction Practice and the need for Change 113
5.9.2 Simplify the Language of Lean Construction 114
5.9.3 Total belief by Site Team and Supply Chain 114
5.9.4 Education 114
5.9.5 Get Clients to insist on Lean Application 115
5.9.6 Publication of Results 115
5.9.7 Reduce the Fear/ Reservations 115
5.9.8 Top Management Involvement and Support 116

5.9.9 Persistence....116
5.9.10 Robust Planning....116
5.9.11 Workers Involvement and Empowerment....116
5.9.12 Government Policies and Legislations....117
5.9.13 Gradual Implementation of Lean Concepts....117
5.10 Implications of Findings on the Conceptual Framework....118
5.10.1 Input....118
5.10.2 Processes (Relationships)....118
5.10.3 Challenges and Strategies for addressing them....121
5.10.4 Negative Impact on Safety....121
5.11 Summary....123
CHAPTER 6: Assessment of the Conceptual Framework: Findings from the Quantitative Study....125
6.0 Introduction....125
6.1 Data Analysis....125
6.2 Survey Response....125
6.3 Characteristics of the Respondents....126
6.4 Characteristics of the Organisations....127
6.5 Testing Components of the Framework....128
6.5.1 Testing for "Negative and Positive Impacts"- Impact of Lean Construction Techniques on Safety....128
6.5.2 Testing the "Processes (Interaction Matrix)"- Potential Impact of Lean Construction Techniques in Reducing Accident Causations....132
6.5.3 Drivers to Lean Construction Practice in Organisations....147
6.5.4 Challenges to Lean Construction Practice in Organisations....150
6.5.5 Outcomes of Lean Construction Practice in Organisations....153
6.5.6 Spearman's Correlations of Drivers and Outcomes of Lean Construction Practice....155
6.6 Summary....156
CHAPTER 7: AN INTEGRATED FRAMEWORK FOR UTILISING LEAN STRATEGIES FOR PROMOTING SAFETY ON CONSTRUCTION SITES....160
7.0 Introduction....160
7.1 Towards Research Outcome....160
7.1.1 Improvement in safety....160
7.1.2 Lean Construction Principles and their applications....160
7.1.3 The Link between Lean Construction Techniques and Safety Issues....162
7.1.4 Challenges....165
7.1.4 Strategies for Overcoming to the Challenges....165

7.1.5 Output 165
7.2 The Framework 166
7.3 Summary 168
CHAPTER 8: RESEARCH VALIDATION 169
8.0 Introduction..169
8.1 Research Validation..169
8.1.1 External Validation..170
8.1.2 Internal Validation 177
8.2 Summary..179
CHAPTER 9: CONCLUSIONS AND RECOMMENDATIONS..181
9.0 Introduction..181
9.1 Summary of the Research Findings 181
9.1.1 Health and Safety Performance of the UK Construction Industry 181
9.1.2 Lean Construction and its Impact on Safety..182
9.1.3 Methodology for Investigating Safety Relevance of Lean Construction Techniques 183
9.1.4 Developing the Conceptual Framework for Utilising Lean Construction Techniques to promote Safety 183
9.1.5 Assessing the Conceptual Framework..184
9.1.6 Integrated Framework..185
9.1.7 Research Validation..185
9.2 Overall Conclusion 186
9.4 Recommendations for Further Research..187
9.5 Recommendations to Policy and Practice..188
REFERENCES 189
APPENDICES 215
APPENDIX A: DETAILS OF PUBLICATIONS 216
APPENDIX B: ETHICAL APPROVAL LETTER..218
APPENDIX C: INVITATION TO PARTICIPATE IN THE INTERVIEW..219
APPENDIX D: INTERVIEW SCHEDULE..220
APPENDIX E: PILOT SURVEY QUESTIONNAIRE..222
APPENDIX F: TYPICAL INVITATION TO PARTICIPATE IN MAIN SURVEY 230
APPENDIX G: MAIN SURVEY QUESTIONNAIRE..231
APPENDIX H: VALIDATION INTERVIEW ON RESEARCH FINDINGS AND OUTCOME..239

List of Figures

Figure 2. 1 Occupational accidents in constructin and other sectors......................................10
Figure 2. 2 Comparing Work-related illness in Construction and other sectors......................11
Figure 3. 1 Last Planner System 36
Figure 3. 2 Conceptual Framework 60
Figure 4. 1 Research Methodology...64
Figure 4. 2 Process Flowchart for Quantitative Data Analysis..88
Figure 5. 1 Developed Framework 122
Figure 6. 1 Position in company 126
Figure 6. 2 Years of working experience..127
Figure 6. 3 Number of employees..127
Figure 6. 4 Average company turn over 128
Figure 7. 1 Framework for utilising Lean Construction Techniques to Promote Safety on Construction Sites 167

List of Tables

Table 2. 1 Causes of accidents 18

Table 2. 2 Classification into Onsite and Offsite Causes of Accidents 20

Table 3. 1 A comparison of Lean practice across sectors 26

Table 3. 2 Lean tools and relevant onsite causes of accidents 54

Table 3. 3 Lean techniques relevant to onsite causes of accidents 56

Table 3. 4 Possible Interaction Matrix of Lean Construction Techniques and Safety issues .. 57

Table 5. 1 Sample characteristic 96

Table 5. 2 2 Lean tools applied 99

Table 5. 3 Drivers for Lean application 100

Table 5. 4 Drivers to Lean practice: comparison with Literature review findings 101

Table 5. 5 Safety Benefits of Lean practice 104

Table 5. 6 Positive Outcomes of Lean Construction practice 106

Table 5. 7 Challenges facing Lean practice in the organisations 108

Table 5. 8 Nature of Challenges facing Lean practice in the organisations 112

Table 5. 9 Challenges to Lean practice in comparison with literature review findings 112

Table 5. 10 Strategies to overcome the Challenges 113

Table 5. 11 Strategies for addressing the challenges in comparison with literature review findings 117

Table 5. 12 Possible Interaction Matrix of Lean Construction Techniques and Safety issues 120

Table 6. 1 Descriptive statistics of the Potential Impact of Lean Construction Techniques on Safety on Construction Site……………………………………………………………...129

Table 6. 2 Frequencies of responses on the potential Impact of Lean Construction Techniques on Safety on Construction Site 131

Table 6. 3 Chi-Square statistics of the Impact of Lean on Safety on Construction Site 132

Table 6. 4 Descriptive statistics of the Impact of Workers Related Techniques on Reducing Accidents Causations 133

Table 6. 5 Frequencies of responses on the Impact of Workers Related Techniques on Reducing Accidents Causations 134

Table 6. 6 Chi-Square statistics on the Impact of Workers Related Techniques on Reducing Accidents Causations 134

Table 6. 7 Descriptive statistics of the Impact of Planning Related Techniques in Reducing Accidents Causations 135

Table 6. 8 Chi-Square statistics on the Impact of Planning Related Techniques in Reducing Accident Causations......136
Table 6. 9 Frequencies of responses on the Impact of Planning Related Techniques in Reducing Accident Causations......138
Table 6. 10 Descriptive statistics of Impact of Tasks Related Techniques in Reducing Accident Causations......139
Table 6. 11 Frequencies of responses on the Impact of Tasks Related Techniques in Reducing Accident Causations......139
Table 6. 12 Chi-Square statistics on the Impact of Tasks Related Techniques in Reducing Accident Causations......140
Table 6. 13 Descriptive statistics on the Impact of Workplace Related Techniques in Reducing Accident Causations......141
Table 6. 14 Frequencies of responses on the Impact of Workplace Related Techniques in Reducing Accident Causations......141
Table 6. 15 Chi-Square statistics on the Impact of Workplace Related Techniques in Reducing Accident Causations......142
Table 6. 16 Descriptive statistics of the Impact of Communication Related Techniques in Reducing Accident Causations......142
Table 6. 17 Frequencies of responses on the Impact of Communication Related Techniques in Reducing Accident Causations......143
Table 6. 18 Chi-Square statistics of the Impact of Communication Related Techniques in Reducing Accident Causations......143
Table 6. 19 Descriptive statistics of the Impact of Visual Management Techniques in Reducing Accident Causations......144
Table 6. 20 Frequencies of responses on the Impact of Visual Management Techniques in Reducing Accident Causations......145
Table 6. 21 Chi-Square statistics of the Impact of Visual Management Techniques in Reducing Accident Causations......145
Table 6. 22 Descriptive statistics of the Impact of the “Other Lean Construction Techniques” in Reducing Accident Causations......146
Table 6. 23 Frequencies of responses on the Impact of the “Other Lean Construction Techniques” in Reducing Accident Causations......147
Table 6. 24 Chi-Square statistics of the Impact of the “Other Lean Construction Techniques” in Reducing Accident Causations......147

Table 6. 25 Descriptive Statistics of the Drivers to Lean Construction Practice in Organisations 148
Table 6. 26 Frequencies of responses on the Drivers to Lean Construction Practice in Organisations 149
Table 6. 27 Chi-Square statistics of the Drivers to Lean Construction Practice in Organisations 150
Table 6. 28 Descriptive statistics of the Challenges of Lean Construction Practice in Organisations 151
Table 6. 29 Frequencies of responses on the Challenges of Lean Construction Practice in Organisations 151
Table 6. 30 Chi-Square statistics of the Challenges of Lean Construction Practice in Organisations 152
Table 6. 31 Descriptive statistics of the Outcomes of Lean Construction Practice in Organisations 153
Table 6. 32 Frequencies of responses on the Outcomes of Lean Construction Practice in Organisations 154
Table 6. 33 Chi-Square statistics of the Outcomes of Lean Construction Practice in Organisations 154
Table 6. 34 Spearman's Correlation Coefficients of Drivers and Outcomes of Lean Construction Practice 155
Table 7. 1 Lean Construction tools and techniques relevant to Safety issues……..………163
Table 7. 2 Potential Interaction Matrix of Lean Construction Techniques and Safety issues 164
Table 8. 2 Feedback on Validity of Findings..174
Table 8. 3 Feedback on the Potential benefit of developed Framework...............................175
Table 8. 4 Feedback on the relevance of the developed Framework....................................176
Table 8. 5 Feedback on challenges and strategies to overcome challenges facing Lean Construction practice 177

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Dedication

This research is dedicated to my parents, Alhaji Muhammad Bashir Abubakar and Hajiya Maimuna Zakariyya.

CHAPTER 1: INTRODUCTION

1.0 Introduction

This chapter presents an overview of the thesis with discussions centered on the research background, its scope and the research questions to be answered. This is followed by a brief discussion on the research aims, objectives and methodology. The main contribution to knowledge and the significance of the research findings are also presented, with the chapter concluding with a summary of how the thesis is structured and organised.

1.1 Background

The construction industry is one of the most significant sectors to the UK government (Ruddock and Ruddock 2011; Fewings 2013). It employs over two million people (ONS 2011) and contributed about 8% of its Gross Domestic Product in 2007 through activities worth £65 billion annually (Hughes and Ferrett, 2008). In 2011, its Gross Value Added (GVA) was £89.5 billion and 6.7% of the total GVA (House of Commons 2012). However, the sector has over the decades recorded high mortality rate of its employees (Hill and Ainsworth, 2001) making it one of the most dangerous industries (HSE 2011; Manu 2012). In the UK, an average of 60 people die annually over the last 10 years on construction sites while 50 suffered fatal injuries in 2010/2011, hence accounting for 30% of all the industries (HSE 2011).

A major aspect of this safety problem is accidents on construction sites. The Health and Safety Executive (HSE) records show that the construction sector has recorded over 50 deaths in 2009/2010 and a fatal accident rate of 2.8 per 100,000 (Fewings 2013). Experience shows that accidents could result in death, major injuries and over 3-day injuries (HSE 2011a). Every year, a large number of workers become temporarily or permanently disabled as a result of accidents on construction sites (Mitropoulos *et al.* 2003; HSE 2012).

Besides the impact on human health, accidents also lead to productivity losses and additional project cost incurred through medical treatment, workers compensation, litigation cost, insurance cost and rehabilitation programmes (Abdelhamid *et al.* 2003; Schafer *et al.* 2008). Furthermore, accidents lead to social costs in the form of emotional and psychological impacts to families, friends and co- workers of the victims (De Saram and Tang, 2005; Ikpe *et al.*, 2006). This has continued to demotivate workers from working in the industry, posing a great threat to its sustainability and to the economy as well.

In an attempt to improve the poor safety performance of the UK construction industry, the government launched a number of campaigns and initiatives such as "Revitalising Health and Safety" and "Turning Concern into Action" where a target was set to reduce injuries by 40% and 65% by 2005 and 2010, respectively (Egan 2002; Oloke *et al.*, 2007; Hughes and Ferrett 2008). Various studies have also proposed different methods and practices, besides compliance with the regulations. These include the Corporate Manslaughter and Homicide Act (HSE 2008), construction methods like prefabrication (McKay 2010), government reports such as the Rita Donaghy Report captioned "One Death is too Many" (Donaghy 2009) and several research studies on safety improvement (Baxendale and Jones 2000; Suraji *et al*., 2001; Cameron *et al*., 2004; Haslam *et al*., 2005; FISCA 2006; Gambatese *et al*., 2008; Shalini 2009). Despite these efforts, accidents still occur on construction sites resulting in the needless death of numerous workers (HSE 2012). Although statistics show a trend of improvement in the safety performance of the industry (Donaghy, 2009), Hoyle (2009) suggests that it may be due to less activities caused by the economic crises. However, these initiatives considered as best practice have yielded to improvement in the industry safety records (HSE 2011), but accidents still occur on construction sites; thus, there are still serious safety problems to be addressed. Hence, the issue of preventing accidents on construction sites has become a significant matter that needs an innovative approach. Furthermore, these initiatives have not considered the potential impact of Lean Construction techniques like workers' empowerment in assignment scheduling, workers' involvement in decision making, workplace organisation and production planning in reducing accident on the UK construction sites.

Lean Construction is a production-based management philosophy that emphasises the elimination of waste from the design and production processes of a construction project using Lean principles first propounded by Ohno (Fewings 2013). It a continuous process of eliminating waste of materials, time, and effort to meet or exceed customer requirements, while focusing on the value stream and continuously pursuing perfection in the project execution (Koskela 2002; Salem and Zimmer 2005). Lean Construction sees accidents as sources of waste of time, money and labour that acts as an obstacle to reliable workflow and value delivery. Thus, accidents need to be eliminated.

Research studies conducted by Houvila and Koskela (1998), Howell and Ballard (1999), Saurin *et al.,* (2002), Thomassen *et al.,* (2005), Salem *et al.,* (2007), Schafer *et al.,* (2008) and Mossman (2009) suggest that the application of Lean Construction techniques on construction sites could help to improve safety on construction sites. However, there is no explicit empirical evidence that relates Lean Construction techniques to safety improvement in the construction industry. Furthermore, the current literature does not give a wholistic view of how Lean Construction techniques could be used to promote safety. It is against this backdrop that this research project is being undertaken to answer the following fundamental research questions:

- How do Lean Construction techniques wholistically relate to safety on construction sites?
- How could Lean Construction techniques be used to promote safety on construction sites?

1.2 Aims and Objectives of the Research

In order to address these research questions, the aims of the research are:

1. To investigate the relationship between Lean Construction techniques and safety
2. To investigate the mechanism by which Lean Construction techniques could be used to promote safety on the UK construction sites.

To achieve these aims, the following research objectives were pursued.

1. To critically review literature relating to safety in order to identify and document causes of accidents and explore how they relate to Lean Construction techniques.

2. To critically review literature relating to Lean principles and techniques from manufacturing and construction industry perspectives in order to identify and document the safety relevance of Lean Construction techniques and practice in the UK.

3. To develop a conceptual framework of how Lean Construction techniques could be used to promote safety on construction sites.

4. To collect data from contracting organisations to examine and test the different

components of the conceptual framework.

5. To develop and validate the integrated framework for using Lean Construction techniques to address safety issues in contracting organisations.

6. To draw conclusions on the relevance of Lean Construction techniques in promoting safety on UK construction sites, and make recommendations to practitioners and for future research.

1.3 Scope of the Research

The research focused on the UK contracting organisations that are engaged in Lean Construction practice. These are companies of different sizes within the UK that are applying Lean Construction principles and tools in their organisations both philosophically and practically within their administrative and site activities. The research studies the relevance of Lean Construction techniques, applied in these organisations, in addressing safety issues particularly causes of accidents on construction sites.

Though Lean Construction principles are applied at both design and construction phases, the role of Lean Construction techniques in promoting safety at the design phase is not covered by the research. Complex and poor designs have a great potential to induce poor safety. However, due to time limitations, the research does not look at the relevance of lean techniques in addressing the safety hazards originating from the designs. The research is limited to the construction phase.

1.4 Research Methodology

The relevance of Lean Construction techniques in promoting safety has remained an issue of significant debate over the last two decades. Whilst a number of researchers and practitioners consider it to be a production system that exposes workers to poor safety, others see it as a way of promoting safety on construction sites, with a number of studies suggesting some lean strategies that could be used to promote safety. However, these are based on little or no empirical evidence. In order to explore the relationship between Lean Construction techniques and safety, based on experiences and understandings of Lean Construction practitioners, the research in the main, adopted a mixed methods approach. The research adopted a pragmatic approach combining both qualitative and quantitative approaches. Prior to the primary data collection phase of the research, ethical approval was sought for and obtained from the University of Wolverhampton's School of Technology Ethics Committee.

For the qualitative study, a phenomenological strategy was adopted, which meant that the experience, opinion and descriptions of Lean practitioners were used to study the phenomenon and develop patterns relating to the relationship between Lean Construction techniques and safety. This was preceded by an extensive literature review to ascertain the antecedents from literature on the relationship. The literature review was carried out using electronic databases, searching of national and international journals, bibliographies of relevant papers, citation search, inter-library loan facilities for relevant materials, textbooks and published Ph.D. theses, with the aim of establishing the current body of knowledge on the potential areas of interaction between Lean Construction techniques and safety in the form of and for the development of a conceptual framework.

Relevant information gathered through the literature search on Lean Construction techniques, safety issues and their interrelationships was analysed, resulting to the development of the conceptual framework. The framework showed how Lean Construction techniques could be used to promote safety in contracting organisations and other issues that have to be considered such as challenges and negative impacts. In order to fully develop the conceptual framework, an exploratory study was undertaken through semi-structured interviews conducted with Lean Construction practitioners from ten (10) contracting organisations. The qualitative data obtained was analysed using thematic content analysis approach and the findings were used to refine the framework.

A survey was undertaken with a sample of 540 Lean practitioners (health and safety managers, project managers and site managers) to help develop and confirm the relationships and concepts presented in the framework. The quantitative study was also used to test the different components of the conceptual framework. The quantitative data was analysed using descriptive statistics, inferential statistics and the inter-rater agreement and statistical significance tests. The Statistical Package for the Social Sciences (SPSS) was used to carry out the descriptive and inferential statistical analysis while the R-software was used to carry out the inter-rater agreement and statistical significance tests.

Based on the findings from the literature review, qualitative and quantitative studies, an integrated framework was developed to guide contracting organisations on how Lean Construction techniques could be used to promote safety on construction sites. The validity and industrial relevance of the framework was established using convergence analysis approach through semi-structured interviews conducted with 5 lean practitioners. Conclusions were finally drawn to clearly show original contribution to body of knowledge and the issues identified were summarised to show how the aims and objectives of the research were achieved. The implications to policy, practice and future research were also stated in the form of recommendations.

1.4 Research Assumptions and Limitations

The following assumptions and limitations underpin the research.

- A number of relationships identified in the literature review were based on logical analysis.
- The study is limited to UK lean practicing contracting organisations.
- Furthermore, only organisations applying Lean Construction as a philosophy were considered as samples for the study (i.e. considered as lean practicing organisations). For example, contracting organisations adopting house-keeping or any other tool and not guided by the principles were not considered as a Lean practicing organisation, hence they were not included in the study.
- Practicing Lean Construction organisations were used as unit of analysis.
- The term “Lean drivers” are used to refer to factors that lead organisations in different sectors to engage in Lean construction practice.
- The term “Lean tools” are used to refer to the different tools developed and adopted from the manufacturing sector to aid the application of Lean construction principles.
- The term “Lean techniques” are used to refer to the different features or practices adopted in applying a Lean construction tool. In other words, Lean techniques are subsets of Lean construction tools. However, in the case of Daily huddle meetings (DHM), which has only one Lean technique, the terms “Lean tool” and “Lean technique” are used as interchangeable words.

1.5 Contribution to Knowledge

There has been much deliberation on the relationship between Lean Construction techniques and safety. While critical observers of Lean Construction suggest that the practice exposes workers to poor safety conditions based on experience from the Japanese automobile industry, advocates of Lean Construction argue that the practice is rather a way of reducing accidents on construction site. Others, however, see the system as a way of reducing project cost and duration and therefore, has nothing to do with safety. The research findings therefore responded to this debate through direct contact with organisations engaged in Lean Construction practice and were therefore based on empirical evidence. The major contributions can be outlined as follows:

- A clear picture of the safety relevance of Lean Construction techniques based on critical literature reviews and interaction with Lean Construction practitioners.
- A clear picture of what drives contracting organisations to engage in Lean Construction practice.
- The development of a framework to guide contracting organisation in promoting safety using Lean Construction techniques.
- Identification of the challenges facing Lean Construction practice in contracting organisations within the UK construction industry and the strategies that could be used to address them.

1.6 Dissemination of the Findings

The research findings and outcome have been disseminated through conference proceedings, workshops, seminars and journal paper publications. A copy of the integrated framework has also been sent to all of the participants in the research. Currently, three conference papers, and two doctoral workshop papers have been published, while 2 journal papers have been submitted. In addition, 3 seminar presentations have been delivered at Lean Construction Institute (LCI) events.

1.7 Structure of the Thesis

The thesis comprises of nine chapters. The first chapter gives an overview of the research. It commences with a background to the research and highlights studies undertaken on the application of Lean Construction techniques to promote safety noting the knowledge gaps. This is then followed by the research aims, objectives, scope of the study and a brief description of the research methodology adopted.

Chapter two reviews the literature on causes of accidents on the UK construction sites and assesses the potential influence of Lean Construction techniques in helping to mitigate them. The chapter, thus, identifies the causes of accidents that could be potentially addressed using Lean Construction techniques to promote safety on sites.

Chapter three reviews literature on Lean practices as applied to the promotion of safety on construction sites. In so doing, the chapter discusses the principles and tools developed to aid Lean practice in the construction industry. The chapter, therefore, teases out the potential relationships between Lean Construction tools and safety issues on the UK construction sites and brings together all the essential aspects to initially conceptualise the mechanism by which Lean Construction techniques could be used to promote safety. As part of the conceptual framework, it presents an interaction matrix of the relationships between Lean techniques and safety issues.

Chapter four presents the research methodology used in conducting the research. In this case, it discusses the qualitative and quantitative approaches adopted in the study, stating reasons why the sequential mixed method approach was adopted. It demonstrates how the data was collected and analysed to address the research objectives

Chapter five presents findings of the qualitative study to ascertain the relationships between Lean Construction techniques and safety, and other related issues from Lean Construction practitioners' viewpoint. Subsequently, the chapter presents a developed framework based on these relationships and those identified from the literature review.

Chapter six presents findings of the quantitative study undertaken to test the relationships identified in the developed framework and other components of the framework.

Chapter seven presents the outcome of the study in the form of an integrated framework. It discusses the different components of the framework and how it could be used by practitioners to promote safety.

Chapter eight presents the validation of the research findings and an evaluation of the relevance of the framework in promoting safety from Lean practitioners' perspective.

Chapter nine discusses the findings across each chapter, and draws conclusions of the study and makes recommendations for policy and practice as well as areas for further extension of the research.

CHAPTER 2: HEALTH AND SAFETY IN THE UK CONSTRUCTION INDUSTRY

2.0 Introduction

The first objective of the research is to critically review literature relating to health and safety in order to identify and document causes of accidents and explore how they relate to Lean Construction techniques. Thus, the chapter begins with discussions on the health and safety performance of the UK construction industry, the legislative framework and Health and Safety Executive (HSE). It also discusses the causes of accident on construction sites and their impact on the industry and concludes with identification of possible linkages/relationships between Lean techniques and onsite causes of accidents.

2.1 Health and Safety Records of the UK Construction Industry

Globally, the construction industry has recorded a poor safety performance in both developed and developing countries (Fewings 2013). Construction activities still result in fatal injuries and the death of its workers (HSE 2012). In the United States of America for example, the sector is responsible for 21% of all occupational related death and 11% of disabling injuries in 2006 (Forbes and Ahmed 2011). Whereas the sector accounts for 20% of work related injuries in Germany (Arndt *et al.*, 2009), a study by Fernandez-Muniz *et al.* (2008) revealed a burgeoning accident rate in Spain in recent years. The fatality rate in construction sector is even higher in Singapore, as it accounted for an estimated 39% of total occupational fatalities in 2006 and contributed an annual accident rate of 9.4 per 100,000 workers in 2008 (Ling *et al.,* 2008). Likewise, in Australia the accident rate is 9.2 per 100,000 workers (Lingard *et al.,* 2009), with too many Australians still being killed and injured every year according to CIC (2009).

In the UK, the HSE records show that the construction sector has recorded an annual average of over 60 deaths annually in the last 10 years (HSE 2011). In the year 2000, the industry suffered up to 84 fatal accidents (Cameron and Duff 2002). In 2001/2002, the injury rate was 4.2 per 100,000 workers which is quite high when compared to an industrial average of 0.88 per 100,000 workers (Hughes and Ferrett 2005). On the whole, the sector has recorded over

2800 work-related death in the last 25 years (Oloke *et al.*, 2007) and 31% of work related death in 2002/2003 (Haslam *et al.,* 2005). On the whole, at least 60000 deaths occur worldwide annually on construction sites, accounting for 17% of total occupational accidents (Fewings 2013). Furthermore, Figures 2.1 and 2.2 demonstrate that the construction sector records a higher rate of work-related illness and fatal accidents compared to other sectors.

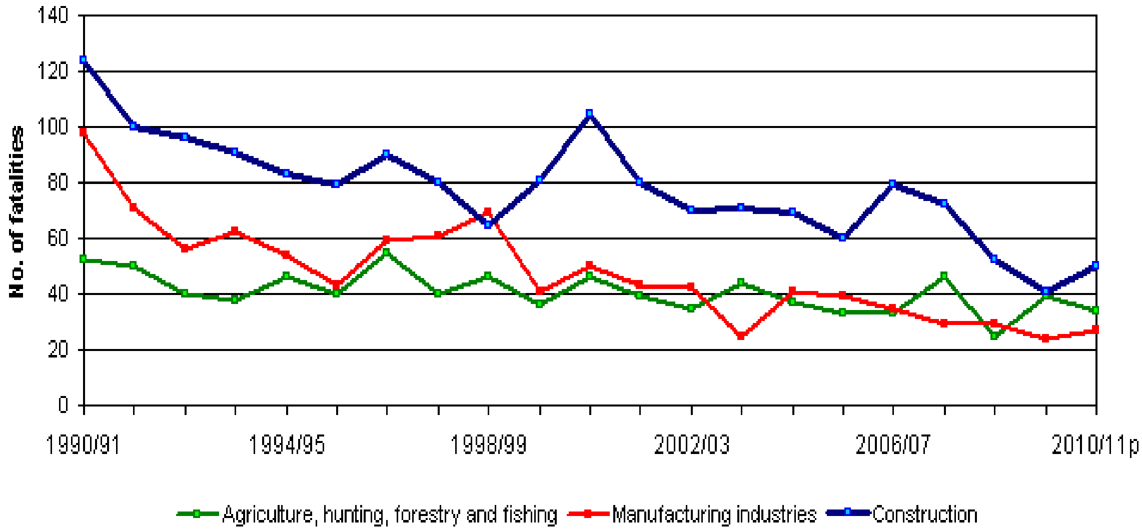


Figure 2. 1 Occupational accidents in constructin and other sectors

Owing to the effort made to improve safety performance in the past decades, there has been a downward trend over the last ten years (Donaghy 2009, HSE 2012) as shown in Figure 2.1. Though the number of occupational accidents remains high, the recent statistics show improvement in the safety records. However, Hoyle (2009) argues that it may be due to fewer activities caused by the economic crises. Still a large number of accidents occurs on construction sites indicating that there are serious safety problems that still need to be addressed. These high accident rates and safety concern pose a great threat to the sustainability of the construction sector itself. Hence, the issue of health and safety in construction organisations has become a serious matter to the government, practitioners, academics and the public in general.

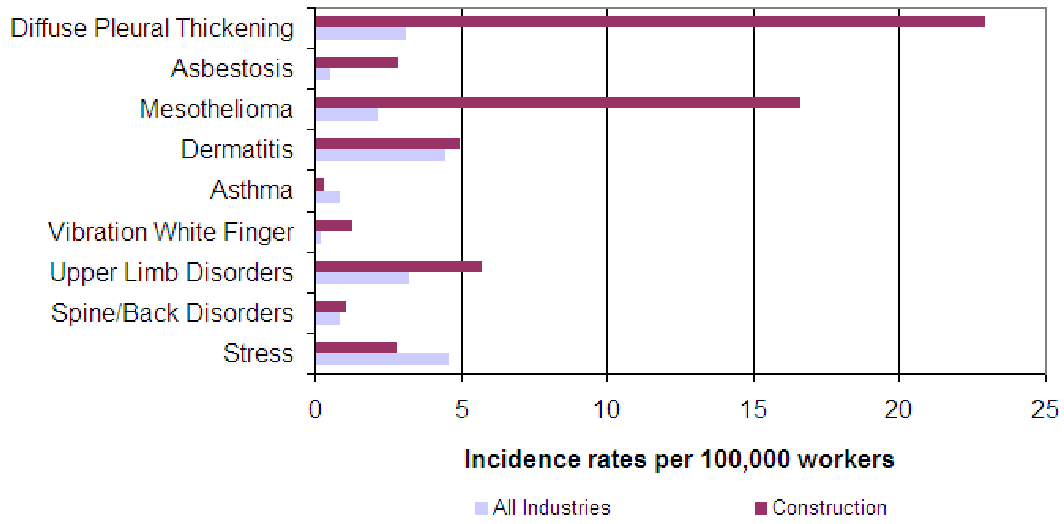


Figure 2. 2 Comparing Work-related illness in Construction and other sectors

Source: (HSE 2011c)

In response to this, the government launched different campaigns such as "Revitalising Health and Safety" and "Turning Concern into Action" where a target was set to reduce injuries by 40% and 65% by 2005 and 2010, respectively (Egan 2002; Oloke *et al.*, 2007; Hughes and Ferrett 2008). Despite these efforts, accidents still occur on construction sites resulting in needless death of numerous workers.

2.2 Legislative Framework

The issue of health and safety legislation in the UK has followed a long trend of development over the past decades. The responsibility for ensuring workers' health and safety stems primarily from the Health and Safety at Work Act (HSWA) of 1974 (Barber 2002; Fewings 2013), though, according to Wolf and Brick (1996), the legal requirement for health and safety in workplaces has been in existence for over 100 years. The HSWA resulted from the findings of the Lord Robens report of 1972 where it was noted that the existing regulations are incomprehensible, ineffective and difficult to reach (Barber 2002). It reviewed the provision of health and safety for workers and made recommendations for the establishment of an act that will ensure general duties and responsibilities in workplaces to protect the health, safety and welfare of workers, employers, visitors, students, members of the public and all those affected by the work (Hughes and Ferret 2007). The report recommended that health and safety regulations should be unified in a single framework that aims at promoting self-regulation rather than enforcing rigid rules (Barber 2002). This led to the introduction of the HSWA in 1974.

Prior to the HSWA 1974, specific duties of ensuring workers health and safety were limited to the employer only (Wolf and Brick 1996). However, with the introduction of the Act, the responsibility is placed on everyone in the supply chain from the designer to the final installer of plants or equipment to be used in the constructed facility (Hughes and Ferrett 2008). It clearly specifies the rights and duties of employers, employees and self-employed in promoting health and safety (Baxendale and Jones 2000).

The HSWA was developed as the main basis for health and safety regulations and statutory framework governing duties and enforcements of health and safety legal requirements in the UK (Barber 2002). The Act embraces the entire framework for health and safety legislation for workers in construction, engineering and other sectors (Wolf and Brick 1996). It served as the foundation for most of the subsequent health and safety regulations. The Act is concerned with protecting the health, safety and welfare of both workers and other people from risks arising out of work activities (Fewings 2013). It also conferred powers on the Secretary of State to make "health and safety regulations" (Barber 2002), which are used to achieve an effective protection of the workers' health and safety. The next section of the chapter discusses the different regulations made over the past decades.

2.2.1 Health and Safety Regulations

The health and safety regulations contain a body of laws which, if strictly obeyed, could significantly promote safety and eliminate poor standards in construction (Donaghy 2009). The purpose of making the regulations is to improve safety and welfare of workers and the public in general. Though the earlier regulations were concerned with preventing accidents and diseases caused by hazards such as noise and chemicals (Wolf and Brick 1996) with focus on the provision of safe working premises (Lingard *et al.,* 2009), recent developments are channeled towards addressing some of the dangers workers are exposed to on site. The new regulations also encourage workers' involvement in decision making on issues relating to health and safety.

The followings are some of the regulations that have come in place, over a period of time spanning decades, mainly in an attempt to achieve safety of workers on construction sites and other workplaces: the Electricity at Work Regulations 1989; Construction (Head Protection) Regulations 1989; Construction Products Regulations 1991; Manual Handling Operations Regulations 1992; the Personal Protective Equipment at Work Regulations (PPE) 1992; Display Screen Equipment Regulations 1992; Reporting of Injuries, Diseases and Dangerous Occurrences Regulations (RIDDOR) 1995; Work in Compressed Air Regulations 1996; Confined Spaces Regulations 1997; Diving at Work Regulations 1997; Work Equipment Regulations 1998; Lifting Operations and Lifting Equipment Regulations 1998; Ionising Radiations Regulations 1999; the Control of Substances Hazardous to Health (Amendment) Regulations 1999; Dangerous Substances and Explosive Atmospheres Regulations 2002; Control of Substances Hazardous to Health Regulations 2002; Control of Asbestos at Work Regulations 2002; Work at Height Regulations 2005; Control of Vibration at Work Regulations 2005; Work at Height Regulations 2005; Control of Vibration at Work Regulations 2005 Control of Noise at Work Regulations 2005; and the Construction Design and Management (CDM) Regulations 1994 and 2007. Though these regulations cover different aspects of construction activities, some organisations can be negligent in complying with them. To aid full implementation and monitor compliance among the construction companies, an executive arm known as the Health and safety executive (HSE) was formed. The next section discusses the role of HSE in promoting health and safety on sites.

2.2.2 Health and Safety Executive (HSE)

The Health and Safety Executive was formed as an executive arm to aid the implementation of health and safety policies and regulations (Wolf and Brick 1996; Hughes and Ferrett 2005). HSE is a complex organisation comprising of different specialist units that provide engineering and scientific advice to trade unions and employers’ organisations (Tyler and Lamont 2008). It also assists in investigating accidents and in commissioning research on health and safety (Tyler and Lamont 2008).

While the local authority welfare officers enforce the regulations at retail and services outlets such as shops, offices, restaurants, residential homes, hotels, garages and entertainment centers, the HSE enforces them at all other work places (Hughes and Ferrett 2005). This is achieved through a network of its inspectors across various regions and areas. The inspectors are empowered to visit industrial premises, construction sites and other workplaces to ensure compliance with regulations (Wolf and Brick 1996). However, according to the Donaghy report (2009), on many occasions, the inspectors visit after the accidents have occurred.

Depending on the nature and location of the construction project, some specialist inspectors may visit the site to ensure compliance with issues such as nuclear installations, mines, explosives, railway and offshore, among others (Tyler and Lamont 2008). Since non-compliance with the regulations is considered a criminal offence, the inspectors are also empowered to issue fines for minor offences and take the case to court for serious offences (Wolf and Brick 1996).

Besides the enforcement role, the HSE issues licenses to specialist contractors such as those dealing with asbestos works (Tyler and Lamont 2008). The HSE provides the most comprehensive information on safety in construction. However, a major problem facing the HSE is the low level of reporting of serious accidents and near-misses which gives an inaccurate picture of fatality rates. As a result, the HSE's statistical records on fatal and major accident rates are based on figures obtained from the Office of National Statistics (Donaghy 2009).

Despite efforts made by the HSE in enforcing these regulations, the safety performance of the construction industry remains poor and unacceptable (Ndekugri and Corbett 2004). Though the regulations and the initiatives have yielded to improvement in the industry safety records (HSE 2011), accidents still occur on construction sites resulting in the death of large number of workers (HSE 2012). Thus, there are still serious safety problems to be addressed. Hence, an innovative approach is required to prevent the occurrence of accidents on construction sites.

The various initiatives introduced by the government to curb the occurrence of accidents on site have not considered the potential impact of Lean Construction techniques like workers' empowerment in assignment scheduling, workers' involvement in decision making, workplace organisation and production planning in reducing accident on construction sites.

2.3 Accidents on Construction Sites

According to the International Labour Organisation, occupational accident is an unexpected and unplanned occurrence, arising due to work and resulting in a personal injury, disease or death to one or more workers (Shalini 2009). Baxendale and Jones (2000) defined accident as "any unplanned event that results in injury or ill health of people, or damage or loss to property, plants, materials or the environment". Similarly, the HSE defined accident as any unplanned event which results in injury or ill health of people, and damage or loss to property, materials, plant, the environment or a business opportunity (Hughes and Ferrett 2008).

The demolition, refurbishment and construction of buildings involve activities carried out using different techniques, machines and equipment that expose workers to different risks and hazards (Egbu 1995, 1999; Hughes and Ferrett 2008). This complexity increases the chances of accidents occurring more regularly on sites. According to Arndt *et al.* (2009), though the working conditions have improved in many developed countries, the activities are still associated with high physical labour due to lifting and carrying of heavy objects, uncomfortable work positions, noise, vibration, dust and climatic influences which could affect workers' health and safety. Other problems associated with sites are continuous change in working environments and nature of works, frequent changes in location, weather effect, materials variation, continuous movement and transportation (Perttula *et al.,* 2003). These factors lead the workers to be involved in different forms of accidents. A critical analysis of studies conducted by Perttula *et al.* (2003), Haslam *et al.* (2005) and Ling *et al.* (2008), showed that these factors have resulted in accidents through falls from height, cuts, being struck by objects, straining, slips and trips, being caught in/between, electric shocks, over-exertion, tumbling, electrocution, and being hit by falling materials.

Falls from height are the most common cause of serious injury or death in the construction industry, accounting for about 50–60 deaths and 4000 injuries each year in the UK (Hughes and Ferrett 2008). About 25% of all deaths at work and 19% of all major accidents are due to falls from a height (Hughes and Ferrett 2005). According to an HSE report, between 2001 and 2004, 722 painters and decorators got injured due to falls from heights (HSE 2005). Some of the most common hazards to pedestrians at work are slips, trips and falls on the same level, falls from height, collisions with moving vehicles, being struck by moving, falling or flying objects and striking against fixed or stationary objects (Hughes and Ferrett 2005). Slips, trips and falls on the same level account for 30% of all the major accidents and 20% of over 3-day injuries reported to the HSE each year (HSE 2004).

Similarly, “being struck by moving, falling or flying objects” causes 18% of fatalities at work and is the second highest cause of fatality in the construction industry causing 15% of all major and 14% of over 3-day accidents (Hughes and Ferrett 2005). Furthermore, striking against fixed or stationary objects accounts for between 1200 and 1400 major accidents each year (Hughes and Ferrett 2008).

Accidents may occur at different locations such as wells, holes, hoists, scaffolds, cranes, ladders, etc (Yousong *et al.,* 2000). Experience shows that accidents could result in three different types of injuries. These are fatal, major and 3-day injuries. A fatal injury is when death occurs within one year of its occurrence or before awarding pension or compensation to the victim (Wolf and Brick 1996), while a major injury is one that leads to hospitalisation of the injured for more than 24 hours (Hughes and Ferrett 2008). As the name implies, a 3-day injury is one that keeps the injured more than 3 days away from work (Wolf and Brick 1996; Hughes and Ferrett 2008).

2.4 Accident Causation Models

Over the past decades, several accident causation models have been developed across different disciplines with each suggesting different root causes for occupational accidents (Manase 2008). Heinrich domino theory of accident causation (1969) considers human behaviour, influenced by social and environmental factors as the root cause of accident. The domino theories were modified by Bird (1974). The modified domino theory (1974) suggested management and organisational factors as the fundamental root causes. Furthermore, Nishishima’s fishbone model (1989) identified the four major root causes of accidents to be human factors, working equipment, nature of work and management roles. However, according to Reason’s tripod model (1990) accidents are initiated by acts such as technical faults, human errors and violation of procedures. In addition, Bellamy and Geyer’s (1992) sociotechnical pyramid of accident causation model suggested communication and feedback control, organisation and management, engineering reliability, operator reliability and psychological climate as the five root causal factors.

On the other hand, whilst Hinze's distraction theory (1996) suggested that accidents originate from physical hazards, production pressures and mental diversion, Rasmussen's model (1994, 1997) identified organisational pressure and individuals' desire to minimise effort as the root causes of accidents. Suraji *et al*. (2001) developed the Constraint-Response model which classified the root cause of accidents into distal and proximal factors. According to the model, the distal factors include constraints and responses that create an atmosphere for accident to occur while proximal factors include inappropriate construction planning, construction control, site conditions, operations and operative actions.

The different causes of accidents presented by the above models are summarised in Table 2.1 and categorised in Table 2.2 into onsite and offsite causes of accidents. Besides accident causation models, a number of studies have also identified additional causes of accidents as discussed in the section below.

2.5 Causes of Accident in the Construction Industry

Several researches have been conducted over decades to further identify the different causes of accidents on construction sites as shown in Table 2.1. While some studies share similar views on certain causes of accidents, some views differ completely. According to Wolf and Brick (1996), accidents occur due to poor project design, poor choice of materials, unsuitable equipment, poorly organised workplace, poor coordination of workers, simultaneous activities, poor training, non-observance of regulations and non-compliance with safety regulations. Furthermore, Sawacha *et al.* (1999) suggest that the poor safety performance of the construction industry is due to lack of knowledge, poor training, lack of supervision, lack of means to carry out the task safely, error of judgment, carelessness, lack of concern, recklessness, nature of the construction industry, the lack of controlled working environment, the complexity and diversity of the organisations, unsafe behaviour, poor safety culture and poor management action. Nevertheless, the study by Tyler and Lamont (2008), views low level of education and lack of proper safety training of workers as the main contributing factors. Ndekugri and Corbett (2004) further identified the fragmented nature of the industry as one of the causes of poor safety performance.

Table 2. 1 Causes of accidents

Causes	**References**
Human, equipment, work and management	Nishishima (1989)
Technical faults, errors and violations	Reason (1990)
Communication and feedback control, organisation and management, engineering reliability, operator reliability and psychological climate	Bellamy and Geyer (1992)
Lack of training, lack of motivation, lack of physical or mental ability, slips and lapses of attention	Kletz (1993)
Poor project design, poor choice of materials and unsuitable equipment, poorly organised workplace, poor coordination of workers and simultaneous activities, poor training, non-observance of regulations and non-compliance with safety regulations	Wolf and Brick (1996)
Lack of knowledge, poor training, lack of supervision, lack of means to carry out the task safely, error of judgement, carelessness, lack of concern, recklessness, fragmented nature of the construction industry, lack of controlled working environment, the complexity and diversity of the size of organisations, unsafe behaviour, poor safety culture, poor management action	Sawacha *et al.,* (1999); Ndekugri and Corbett (2004)
Management deficiency, training and workers' attitude	Abdelhamid and Everett (2000)
Lack of adequate training, increased number of self-employed operatives, increased use of subcontractors and blurring responsibility for Safety personnel	Hill and Ainsworth (2001)
Inappropriate construction planning, construction control, site conditions, operations and operative actions	Suraji *et al*., (2001)
Poor organisational culture	Molenaar *et al.*, (2002)
Lack of proper training, inadequate safety equipment, poor enforcement of safety requirements, unsafe equipment, poor safety attitude	Toole (2002)
Management failures	Cameron and Duff (2002); Cameron *et al.*, (2004); Fang *et al.*, (2004)
Site hazards, human actions and functional limitations	Mitropoulos *et al.*, (2005)
Lack of site awareness, incompetence, fatigue, poorly organised working environment, poor planning, unsuitable tools and equipment, poor communication and non-compliance with procedures	FISCA (2006)
Poor supervision, poor communication, poor training, poor selection of contractors	Anumba *et al.*, (2004); Hughes and Ferrett (2008)
Low level of education and poor safety training	Anumba *et al.*, (2004);Tyler and Lamont (2008)
Human error	Fang *et al.*, (2004); Hughes and Ferrett (2005); Mitropoulos *et al.*, (2005); Katsakiori *et al.*, (2009)
Lack of knowledge	Donaghy (2009)

A critical analysis of research conducted by Hill and Ainsworth (2001) and Yousong *et al.,* (2002) found other factors like economic difficulties, unemployment, reduced training, increased numbers of self-employed site operatives, the increased use of subcontractors and the blurring of responsibility for health and safety of personnel on site, as contributors of accidents causation. In addition to these, other factors that are associated with accident causation include poor supervision, poor communication of information, poor training, poor selection of contractors (Anumba *et al.,* 2004; Hughes and Ferrett 2008), lack of training, lack of motivation, lack of physical or mental ability, slips and lapses of attention (Kletz 1993), hazards, human actions and functional limitations (McClays 1989), management deficiency, training and workers' attitude (Abdelhamid and Everett 2000), organisational culture (Molenaar *et al.,* 2002), lack of proper training, inadequate safety equipment, poor enforcement of safety requirements, unsafe equipment, poor safety attitude (Toole 2002), management failures (Cameron and Duff 2002; Cameron *et al.,* 2004 ; Fang *et al.,* 2004) poorly communicated procedures, poor verbal communications, missing or incorrect signs (Hughes and Ferrett 2005) and lack of knowledge (Donaghy 2009).

Several researches found human error as a major contributor to accidents (Fang *et al.,* 2004; Mitropoulos *et al.,* 2005; Katsakiori *et al.,* 2009). This is contained in the report of the HSE Accident Prevention Unit which also showed that 90% of all accidents are due to human error and 70% of all accidents could have been avoided had the management been proactive (Hughes and Ferrett 2005). However, research conducted by FISCA (2006) found that the most common causes of accidents are problems associated with site awareness, competence, fatigue, working environment, planning, tools and equipment, communication and procedural issues.

As the research aims at investigating the mechanism by which Lean Construction techniques can be used to promote safety on construction sites, there is need to identify those causes of accident that are related to the construction site. Thus, Table 2.2 categorises the causes of accidents presented in Table 2.1 into onsite and offsite causes as dicussed below.

2.6 Onsite and Offsite Causes of Accidents

As the name implies, the offsite causes of accidents occur outside construction sites. They do not occur on site because they have no direct involvement with the operational work onsite. They are not generated by site activities. For instance, complex or poor designs are part of causes of accidents (Wolf and Brick 1996; Haslam *et al.,* 2005). However, they occur outside the site and are not generated by site activities. However, they also affect the timely and healthy delivery of construction projects. On the other hand, onsite causes of accidents are those that are directly associated with operations on site (e.g. site congestion). They could result in accident by creating hazards such as dust, noise, excessive stress, slips, trips, poor visibility and congestion (Hide *et al.*, 2003; Brace *et al.*, 2009). They could also be attached to the working environment, for instance bad weather conditions (Suraji *et al.,* 2001; Haslam *et al.,* 2005). Table 2.2 presents a classification of the causes into onsite and offsite causes.

The onsite causes of accident relate to the working environment, the worker, the site equipment and management issues. As the application of Lean Construction principles and techniques on site encompasses these different aspects, the research focusses on exploring the safety relevance of Lean Construction techniques along these aspects. Based on this, table 2.2 was prepared.

Table 2. 2 Classification into Onsite and Offsite Causes of Accidents

Onsite causes of accidents	**Offsite causes of accidents**
Poor work methods	Poor project design
Excessive stress	Fragmented nature of the construction industry
Judgement errors	Poor safety culture
Poor site supervision	Poor top management action
Site congestion	Poor selection of contractors
Physical and mental disability	Economic trends
Fatigue	Growth in unemployment
Poor planning and control	Increased use of subcontractors
Poor coordination of workers	Increase in self-employed operatives
Poor coordination of simultaneous activities	Complexity of organizations
Poor communication	Diversity of organizations
Time pressure	
Lack of site awareness	
Organisational pressure	
Human error	
Non-compliance with procedures	
Poor safety training	
Poorly organised workplace	
Unsafe behavior	
Equipment failure	
Site hazards	
Inadequate personal protective equipment	

2.7 Lean Construction as a Strategy for Reducing Onsite Causes of Accidents

Lean Construction is a way of designing production systems to minimise waste of materials, time and labour in order to generate the maximum possible amount of value for the client (Abdelhamid and Salem 2005; Song *et al.* 2008). It considers safe work practice as crucial to achieve reliable workflow in construction operations (Teo *et al.* 2005; Schafer *et al.* 2008). Hence, accidents are seen as a major source of waste that acts as an obstacle to reliable workflow and value delivery.

Howell and Ballard (1999) suggest that implementing Lean Construction principles and tool could help in reducing accidents on site. For instance, by improving efficiency, cycle times and materials handling, wastage and consumption are all reduced. This in turn reduces workers' exposure to hazardous materials, chemicals, dust, noise, biomechanical hazards, and similar construction site hazards. Furthermore, Salem *et al.* (2007) noted that the application of lean tools such as 5S (house-keeping) could reduce hazards such as slips, trips and falls which are the major onsite causes of accidents. Therefore, Lean Construction principles and tools have potential to improve safety in construction organisations. However, there is no empirical evidence to support this assertion (Nahmens and Ikuma 2009).

Despite these positive assertions, several critical observers of lean production suggest that the system, which originates from the Japanese Toyota automobile company, has a poor approach to safety and human resource management (Green 2001). Studies such as Fucini and Fucini (1990), Garrahan and Steward (1992), Rehder (1994) and Turnbull (1998) associated the system with excessive stress, exploitation, surveillance and poor quality of life. Similarly, Fucini and Fucini (1990) and Rehder (1994) suggest that the system exposes workers to poor safety standards and lack of freedom in the automobile industries. In this respect, the research will explore the phenomenon to investigate the positive and negative impact of Lean Construction practice on safety.

2.8 Summary

Despite the importance of the construction sector to the UK, it has remained one of the most dangerous sectors due to its high record of injuries and death mostly caused by accidents. The poor safety performance poses a high social and economic cost on the workers, employers and the government. In spite of attempts to tackle this problem through formulation of various Acts, regulations and campaigns, the poor safety record still remains unacceptably high.

The chapter reviewed the different accident causation models and causes of accidents on construction sites and found two main causes of accidents on construction sites namely: onsite and offsite causes. Even though there is no empirical evidence, it was noted that various studies suggested the implementation of Lean Construction tools as a strategy for redressing onsite causes of accidents such as excessive stress, slips, trips, falls, dust, noise, poor communication, poor visibility, and congestion, among others. However, a number of studies argued that the tools have negative impact on safety.

Despite these arguments, studies on the application of Lean Construction techniques in preventing accidents have been marginal. It is therefore to deepen our understanding of how Lean Construction techniques could aid in the reduction of accidents on construction sites or otherwise that this study is pursued. To achieve a systematic enquiry, it is imperative that the concept of Lean thinking and its application in the construction sector be first understood from the literature point. Besides addressing on this, the next chapter studies the integration of Lean Construction tools and onsite causes of accidents.

CHAPTER 3: THE APPLICATION OF LEAN THINKING IN THE CONSTRUCTION SECTOR AND ITS SAFETY IMPACTS

3.0 Introduction

The second objective of the research is to critically review literature relating to Lean principles and techniques from manufacturing and construction industry perspectives in order to identify and document the safety relevance of Lean Construction techniques and practice in the UK. The chapter commences with a discussion on the origin of lean thinking and how it was developed from the Toyota production system and adopted across non-automotive sectors. The chapter further presents reviews on Lean Construction principles and tools in order to identify their safety impacts and the challenges facing Lean Construction practice. It then demonstrates the linkage between Lean Construction techniques and safety with reference to accidents on construction sites and finally devises a conceptual framework.

3.1 The Concept of Lean Thinking

The success of the Toyota production system is attributable to the application of lean thinking to eliminate all forms of waste (Egan 1998; Koskela 2004; Forbes and Ahmed 2011). Though Lean thinking lacks a universal definition (Bayou and Korvin 2008); it has been defined as a way of reducing lead time and operational cost by minimising waste and improving employee's skills, performance and satisfaction (Creese 2000). It is a philosophy that rejects all forms of waste and continuously strives to avoid defects (Dickson *et al.,* 2007). Beyond eliminating waste of time, labour and materials, it also focuses on delivering value to the customer from inception to completion and from design to final handing over of the project (Fewings 2013). By so doing, the application of lean thinking leads an organisation to be continuously engaged in activities that add value to their product while eliminating, as much as possible, activities that add no value (Dickson *et al.*, 2007). The philosophy emphasises that all the operations of an organisation should be continuously evaluated to identify and minimise waste and inefficiencies (Forbes and Ahmed 2011).

The concept of Lean thinking was developed from the 1950's in Toyota out of necessity and shaped by historical events (Liker 1998; Faniran *et al.*, 1997). During the Second World War, the Japanese economy was heavily devastated leading to a scarcity in business capital which disrupted car production (Nicholas 1998; Moody 1999). The post war economic difficulties also resulted in large inventory of unsold cars, with the market being seriously brought down by low income and demand, leading to further financial crisis at Toyota (Holweg 2006). The space and capital constraint made the practice of mass production of cars impossible for Toyota (Koskela 1992; Liker 1998). It also made it impossible for the company to invest in modern equipment and technology despite the challenge posed by the need to produce wide variety of cars that could compete with other car manufacturers and satisfy customers (Nicholas 1998; Womack and Jones 1996). The struggle to accomplish, maintain, and keep efficiency has been very difficult for Toyota resulting in Taichii Ohno making Toyota production managers to adopt some elements of mass production system (Liker 1998; Holweg 2006). Ohno developed a production system that will produce only what is needed without engaging in non-value adding activities considered to be a waste (Forbes and Ahmed 2011). He identified overproduction, waiting, transportation, processing, inventory, movement as well as making defective products as major sources of waste in the production system and worked towards eliminating the waste they generate across all aspects of the production process (Bertelsen 2004; Fewings 2013).

To facilitate waste elimination, Toyota used methods like pull scheduling, buffer reduction and simplified operations (Salem and Zimmer 2005). The concept evolved tools like the Kanban, Poka-yoke and Kaizen among others, and manufacturing methods such as Just-in-time and Total Quality Management (Koskela 1993; Forbes and Ahmed 2011; Fewings 2013) with standardization of operations and employee involvement and empowerment in all improvement activities (Dickson *et al* 2007). The system also embarked on different techniques such as kaikaku, visual management and poka-yoke (error-proofing), among others, that could help in reducing resources required to produce a product (Moody 1999). Thus, it could be said that the techniques were not new, but rather they were existing techniques that were combined and used in a different way. While a lot of these methods have been applied previously, in fact as far back as a decade earlier (Schonberger 2006), the lean principles under which they are applied were developed in Toyota (Forbes and Ahmed 2011). However, despite the numerous advantages of the lean approach and principles, Fuccini and Fuccini (1990) argued that workers were neither empowered nor made autonomous by the system.

3.2 Application of Lean Thinking in Non-Automotive Sectors

In an attempt to gain competitive advantages, both automotive and non-automotive organisations have continued to seek different ways of optimising their operational efficiency, quality, speed, control and flexibility among others (Bayou and Korvin 2008). Though the attainment of these goals has become increasingly complex, Liker (1998) considers the application of lean thinking as an effective and efficient way of managing this complexity. While Egan (1998) and Koskela (2002, 2004) believe that the concept could be applied in non-automotive sectors like construction to manage the supply chain, design new products and provide services, Kenney and Florida (1993) observed that the lean production system is an end product of a long term transformation process at the Toyota car manufacturing plant. As a result, its adoption in other sectors or industries should not be expected to always deliver the same benefits realised in Toyota (Garnett *et al.,* 1998). Nevertheless, according to Womack and Jones (1996), a good understanding and application of the lean principles can enable managers in other business sectors to achieve a steady improvement in their operations. It has been successfully adopted in construction (Salem *et al*., 2005), aerospace (Haque 2003), electronics manufacturing (Doolen and Hacker 2005) and health sectors (Dickson *et al*., 2007). Table 3.1 presents a summary of the application of Lean thinking across five different sectors. These include aerospace, health, construction, electronics and processing. The table shows the different Lean techniques they adopt in attaining their targets in respect to the various Lean drivers.

Lean drivers are factors that lead organisations in different sectors to engage in Lean practice. They are the organisational purpose of applying Lean principles and techniques. As shown in table 3.1, these drivers vary across the sectors. For instance, cost reduction benefits, improving efficiency, improving product and services quality, time reduction benefits, increasing revenues and clients' satisfaction are among the factors that drove UK contracting organisations into Lean practice (Bashir et al., 2013).

Table 3. 1 A Comparison of Lean Practice across Sectors

Sectors	**Lean concepts applied**	**Lean Drivers**	**References**
Aerospace	Continuous improvement activities, customer focus, enhanced visibility, waste elimination, supplier involvement, standardisation, cross-functional teams, strategic management, customer involvement, systems engineering, design for lifecycle, information and process flow optimization, lean behavioural change	Eliminate waste of resources and non-value adding activities, develop detailed designs, minimise variation, avoid rework, reduce cost, poor military market.	Crute *et al.*, (2003); Haque (2003); Bayou and Korvin (2008)
Health	Kaizen events involving frontline workers, hospital managers and customers; workers' empowerment; work standardisation; value stream mapping, Just-in-time; 5S and 5 Whys, waste elimination, error-proofing techniques, process mapping, value stream mapping, functional flow redesign	Continuous rise in health care cost, inefficiencies in health care delivery, delays, more space creation, improvement in patients' flow, patients' satisfaction and patients' visits, reduce overcrowdings, work disruption	Kim *et al.*, (2006); King *et al.*, (2006); Dickson *et al.*, (2007) ; Dickson *et al.*, (2009); NHS (2009)
Construction	Last Planner System, Increased visualisation, the 5S (housekeeping), Error-proofing, First run studies and Daily huddle meetings	Decline in profit margin, increased competition, low customer satisfaction, cost overrun, time overrun, elimination of non-value adding activities	Egan (1998); Abdelhamid and Salem (2004); Salem *et al.*, (2005)
Electronics	Total quality management, Just-in-time, Error proofing, customer involvement in product design, total product management, cellular manufacturing, set up reduction, levelled production, teamwork, design for manufacturability, on-time deliveries, workplace organisation, concurrent engineering, waste reduction, continuous improvement, visual management, work flow and human resource management	Changing economic conditions; high level of uncertainty in demands; low-volume product policies, rapid increase in customer expectation; high pace of technological change and competitive global market; to improve performance in terms of cost, operations and organisational structure; to improve production planning and control, process technology, workers' management, organisational structure and facilities management	Doolen and Hacker (2005);
Processing	Just-in-time, kanban, total production maintenance, total quality management, 5S, production smoothing, set up reduction and cellular manufacturing	Demand for improvement activities, competition	Abdullah and Rajgopal (2003); Abdelmalek and Rajgopal (2005)

3.3 Lean Construction

Koskela *et al.* (2002) defined Lean Construction as a way of designing the construction production system with the least waste of materials, time and effort in order to generate the maximum value achievable. The concept was also defined by Salem and Zimmer (2005) as the continuous process of eliminating waste to meet or exceed customer requirements, while focusing on the value stream and continuously pursuing perfection in the project execution. According to Abdelhamid and Salem (2004), a widely used definition is that Lean Construction is a way of designing production systems to minimise the waste of materials, time, and effort in order to generate the maximum possible amount of value for the client. Fewings (2013) recently defined Lean Construction as elimination of waste from the design and production processes of a construction project using Lean principles first propounded by Ohno. By minimising activities that do not add value to the product and services and creating more time for those that add value, Lean Construction maintains a continuous pursuit of improvement throughout the design, construction, operation and maintenance stages of a construction project to satisfy the client’s requirements. In addition to making the construction process more effective, efficient and profitable, it brings effective value and risks management into construction companies and challenges the belief that cost, time and quality management cannot be concurrently pursued (Dulaimi and Tanamas 2005).

3.4 Lean Construction Principles

Lean thinking has five basic principles that are crucial to achieving both market acceptance and operational excellence. Womack and Jones (1996) first identified the five lean principles as; identifying value from the customer point of view; understanding the value stream; achieving flow within the work process; achieving customer pull at the right time; and striving for perfection and continuous improvement (Cullen *et al*., 2005; Hook and Stehn, 2008; Suresh *et al*., 2012; Fewings 2013). These principles are drivers for continuous improvement and the benefits of Lean Construction can only be achieved through their wholistic implementation (Dulaimi and Tanamas, 2005). However, according to Green (2001) and Bertelsen (2004), not all the principles are applicable to construction due to the difference across the sectors. Nevertheless, Forbes and Ahmed (2011) suggested that the five principles are applicable to all organisations. Similarly, whilst Salem and Zimmer (2005) observed that most of the principles have been proven to be applicable to construction industry, Koskela (2004) noted that they do not thoroughly cover value generation aspects of a production process. Furthermore, Hook and Stehn (2008) also opined that the principles lack focus on cultural aspect of the workforce, which is an inevitable part of lean practice. Due to the peculiar nature of construction processes, which varies from manufacturing, Koskela (1992) outlines Lean Construction principles as: process transparency; variability reduction; cycle-time's reduction; simplicity; benchmarking; output flexibility; flow management; and focussing on complete process. On the other hand, the Construction Industry Institute (CII) identified five different Lean Construction principles as customer focus; culture and people; workplace organisation and standardization; elimination of waste; and continuous improvement and built-in quality (Forbes and Ahmed 2011). To enhance an understanding of Lean Construction, a discussion of the principles is vital.

3.4.1 Value Identification

In Lean Construction, value is looked at from the customer point of view and it is defined by the customer's needs and satisfaction requirements (Koskela 2004). Value should be easy and possible to understand and specify and should be provided at the right time and cost (Bjornfot and Stehn 2007; Mossman 2009). Because the efficient delivery of value to the client is a primary concern that governs the whole transformation process, Lean Construction aims at managing all value adding processes (Bjornfot and Stehn 2007). Thus, in order to achieve adequate value adding processes, an organisation should be involved in activities that will transform the deliverables of the project in a way that the client appreciates the transformation and is prepared to pay for it (Mascitelli 2002). The client requires a product that fulfills its purpose, meets the client's requirement and represents value for money (Ballard and Howell 2004). The UK government reports have shown that for companies to remain competitive, they must know what the client wants and expect to get in return (Fewings 2013). Therefore, the supply team must know the needs of the client as well as end users of the product to effectively deliver value.

3.4.2 Value Stream Map

Every project has deliverables which require value and a client who receives the value. The delivery of a construction project comprises of both value adding and non-value adding activities. Whereas the value adding activities convert the materials into the product, the non-value adding activities consume resources like time, space and money without adding value to the product (Farrar *et al.* 2004; Forbes and Ahmed 2011). And though a research study conducted in Sweden by Bjornfot and Stehn (2007) showed that only 20% of construction activities directly add value to the product, the findings of a study by Koskela (1992 in Seneratne and Wijesiri 2008) revealed that non-value adding activities consume about 12% of total project cost and 2/3 of total project time. Therefore in order to effectively and efficiently develop and deliver a product, there is need to identify all the essential value-adding steps. The value stream comprises all the value-adding steps required to design, produce and provide the product (Fewings 2013). In construction, the value stream is a sequence of activities ranging from the concept to handing over so that the client demands (pull) the building or services. Identifying the value stream involves establishing when and how decisions are to be made and the main strategy behind it to understand how value can be built into the building. The value stream map is therefore an outline of operations that lead to valuable achievement of product and identifies alternative routes to maximise performance in the construction process (Dulaimi and Tanamas 2005; Forbes and Ahmed 2011).

3.4.3 Flows

Lean Construction aims to achieve an effective flow of information and resources. Flow is a key process of perfecting and balancing the interconnected activities through which a product can be developed (Fewings 2013). However, there are a number of factors that could pose as obstacles to the flow of value adding activities and resources in a construction project. These include accidents, executive meetings, poor communication, approval cycles, poor welfare on site, variations and management interference and waste, among others (Mascitelli 2002, Abdelhamid and Salem 2005). Therefore, the aforementioned obstacles must be minimised in order to achieve a successful delivery of the created value to the customer. Construction practice is seen to be highly wasteful and a waste free flow of tasks and activities is necessary to create value for the client (Latham 1994; Forbes and Ahmed 2011). With this in mind, different lean techniques that seek to eliminate stages hindering flow of value-adding activities are being developed in order to eliminate any obstacle to flow of value through out the construction process (Bennett 1998; Farrar *et al.* 2004). This involves minimising uncertainties, reducing accidents, avoiding variations and in some cases re-planning the works so that some tasks can proceed without necessarily completing others.

3.4.4 Pull

Pull is the ability to deliver the product to the client at the earliest possible time (Bicheno 2000). The delivery of a construction project constitutes several risks and uncertainties which hinder the delivery of a product to the client within the shortest period and using the minimum resources (Dulaimi and Tanamas 2005). However, this could be avoided by an immediate definition of the client's needs and requirements so that the customised product can be subsequently delivered to the client within the shortest period using the minimum material, labour, designs and other required resources. The building materials must also be supplied as soon as they are needed to prevent the project from slowing down (Farrar *et al.* 2004). To achieve a pull, the project team should clearly make the client understand how the deliverable solves all his problems and allow the client to pull the product himself (Mascitelli 2002; Farrar *et al.* 2004).

3.4.5 Perfection

To attain perfection, improving performance in an organisation and continuous improvement must be made a culture. This requires persistent identification of what valuable tasks, how they should be done and matching tasks with the right teams to execute them. Perfection can be achieved through a continuous improvement in eliminating all forms of obstacles and non-value adding tasks along the flow process (Dulaimi and Tanamas 2005). The principle of perfection involves producing exactly what the customer wants in terms of quality and quantity at the right time at a fair price and with minimum waste; the real target is zero waste (Bicheno, 2000). The principle emphasises waste elimination is never finished i.e. it is continuous and this makes Lean Construction a journey rather than a process.

3.4.6 Process Transparency

Process transparency could simply be defined as process visibility (Klotz and Horman 2007). It is one of the foundations of lean production. The principle emphasises that the production process and its parts should be able to communicate with the people (Formoso *et al.*, 2002). The management and the workers should be able to easily read and recognise the status of all the processes and activities going on on the site (Tzortzopoulos and Formoso 1999). Visual devices, signage, house-keeping and good layout could all be used to make the entire processes directly observable to the workers, management and all stakeholders on the site

(Tezel *et al*., 2010; Forbes and Ahmed 2011). The work settings should be made self-explanatory. Process transparency reduces chances for error to occur and facilitate the visibility/ identification of errors and defects in the process or product (Koskela 2000). Continuous improvement across the different aspects of the production process can only be achieved when the presence of waste, abnormalities or problems are identified by people working on the site. The process should be transparent and communicative for everyone to identify, amend and avoid a problem or prevent it from reoccurring. Furthermore, it is only when the process is transparent that value creating activities can be generated and non-value creating activities can be minimised.

3.4.7 Benchmarking

This is a systematic and logical way of improving the performance of the production system by measuring and comparing performance of the organisation with other organisations, so that lessons can be learnt from the best system to make further improvement (Constructing Excellence 2012). It identifies which approach is the best and what can be done to achieve similar or better performance. Lessons could be learnt from comparison with construction organisations or even from other industries (Koskela 1992; Costa *et al*., 2004). Lessons learnt could be used to reflect improvement in working culture, processes, performance and productivity. This could involve developing a programme to achieve targeted improvements across the different areas. Benchmarking enables the organisation to look externally beyond its own internal improvement strategies (Alarcon *et al* 2001). The principle emphasises that companies should discuss and share their best practices in operations management and resources management, so that they can learn from one another.

3.4.8 Cycle time reduction

When an organisation engages in continuous improvement activities, the time taken to perform activities and tasks should be reduced. This could be achieved by reducing the overlaps between activities, waiting times, transportation or movement times, queue times and the activity duration itself (Koskela 1992; Ballard 2001). In order to achieve these reductions, the workers should be as efficient as possible. Furthermore, the workflow reliability needs to be maximised. However, to maximise the workflow reliability, the variability has to be minimised (Ballard 2001).

3.4.9 Flexibility

A reasonable level of flexibility in the production system enables the organisations, clients and workers to easily respond to changes and unpredicted demands which could arise due to technology, market conditions or needs to improve efficiency (Lane and Woodman 2012). No matter the certainty and low level of variability, a provision should be made for flexibility in the processes. The level of flexibility could vary across different aspects of the production system. This should be determined and relatively provided depending on the nature of the process. The level of flexibility needed in a process/ task depends on the level of predictability possible. A higher level of flexibility is required in tasks where there is low level of predictability compared to tasks with high level of predictability (Lane and Woodman 2012). However, Tzortzopoulos and Formoso (1999) suggest that adequate care should be taken to ensure that attempts to improve the project flexibility do not cause disruptions to project execution/ delivery/ production process.

3.4.10 Balance Flow Improvement with Continuous Improvement

Lean Construction categorises construction activities into conversion and flow activities (Koskela 1992). The flow activities include material flow, workflow, information flow and so on. The effective management of these flows creates a safer, more efficient and productive project delivery. Thus, flow management is a very significant component of Lean Construction practice. Emphasis should therefore not only be focussed on improving conversion processes alone, rather improvements efforts should also be focussed on the flow activities. Both flow and conversion activities should be integrated (Tzortzopoulos and Formoso 1999). This enables the achievement of a balance in both flow and conversion activities (Chen *et al.*, 2004). Furthermore, in flow management, flow conflicts and unnecessary flows should be avoided to save resources.

3.4.11 Process Simplification

This principle emphasises that the production process should be made as simple as possible by reducing the number of steps, parts and linkages which could reduce the project cost and reduce the chances of errors and problems occurrence (Tzortzopoulos *et al.*, 1999). Unless necessary, complex work methods and programmes should be avoided as far as the project objectives can be met. Simple methods should be adopted in delivering valuable products and services to the client. The number of steps and tasks involved should be reduced as much as possible without comprising the value, quality and other projects objectives (Chen *et al*., 2004). Similarly, the number of steps and linkages involved in the flow of materials and information should be reduced to minimise non-value adding activities. Advanced technologies may also be used to simplify the task execution and facilitate task execution and management of both conversion and flow activities (Chen *et al*., 2004).

3.4.12 Minimise Variability

Variation is a non-value adding activity which can result in waste of resources, workflow unreliability and even a possible overrun of project cost and duration (Kraemer *et al*., 2005). Though variability is unlikely to be avoided in project delivery, it should be minimised as much as possible due to its great negative impact of the project performance. Variability could affect the project success by resulting in lost output, increase in lead time, wasted capacity and high level of work-in-process. The negative impact of variability on the project is higher at later stages of the project compared to early stages (Koskela 2000). Therefore, more efforts should be put to prevent variability as the project moves towards completion. The more consistent and “on target” the project processes are, the more satisfied the client becomes and the earlier the project is completed and thus the less stressed the workers may become. Variability can be prevented through detailed planning of activities to be carried out as the tasks approaches (Tzortzopoulos *et al*., 1999), for example through weekly work planning and daily huddle meetings.

3.4.13 Focus on Complete Process

The focus should be on the whole process not only on parts of it. Though progress is checked across different activities going on on the site, the progress check, evaluations and monitoring should be done automatically across all aspects of the project (Tzortzopoulos *et al*., 1999). However, individual parts and tasks should also be planned and designed in details so that appropriate resources will be allocated to minimise waste and maximise efficiency.

3.4.14 Build Continuous Improvement into the Process

A continuous improvement culture should be instilled in the workers. The principle pursues managers and workers, to participate in continuous improvements activities of the organisation (Senaratne and Wijesiri 2008). Both employers and employees should constantly be involved in a well-planned, systematic, never-ending and innovative reduction of waste and inefficiency (Abdelhamid and Salem 2005; Forbes and Ahmed 2011).

3.5 Lean Construction Tools and Techniques

Lean Construction does not imply the imposition of Lean manufacturing techniques on construction process (Forbes and Ahmed 2011), but rather the development of techniques and tools that conform to Lean construction principles and applying them in project delivery (Abdelhamid and Salem 2004). According to Paez *et al*. (2005), the fundamental differences between manufacturing and construction processes in terms of the operations, planning and task execution makes it impossible for Lean manufacturing tools to be directly implemented in construction.

Koskela (1997) and Fewings (2013) identified construction as “one of a kind” site production with many specialist subcontractors. Similarly, Ballard and Howell (1998) describe it as a unique and dynamic process. Furthermore, manufactured products are movable and produced in a fixed workplace unlike construction which is faced with more challenges and uncertainties, such as weather, hence demanding for more robust responses (Fewings 2013). Owing to these dissimilarities, a new set of tools that will suit construction processes had to be developed (Salem *et. al* 2005). Construction academics and professionals have developed and successfully applied Lean Construction tools to simple and complex construction projects (Abdelhamid and Salem 2004). These tools were applied across different stages and aspects of the delivery process ranging from design, work structuring, project management, delivery system down to supply chain and project controls. This is exemplified by Tsao *et al.* (2000)’s illustration of how the Lean principles improved the design and installation of metal door frames in the construction of a prison. Thus over the years, the construction industry has adopted some Lean production tools and further developed more to improve the performance of the construction process based on Lean principles. The most developed Lean Construction tools, according to Salam *et al.* (2005), are the Last Planner System; increased visualization; daily huddle meetings; first run studies; the 5S (house-keeping), and error-proofing.

Lean construction techniques are the different features or practices adopted in applying a Lean construction tool. In other words, Lean techniques are subsets of Lean construction tools. A Lean construction tool comprise of one, two or more Lean techniques. For instance, the tool 5S (house-keeping) comprises of Lean techniques such as clean workplace (Seiri), and tools and materials organisation (Seiton). Similarly, under the tool Last Planner System, the Lean techniques adopted are workers' empowerment in assignment scheduling, correlating work methods with workers' skills, correlating tasks with workers' ability, pre-task hazard analysis, weekly work planning, and workers involvement in task planning. However, in some cases, the Lean tool has only one feature. For instance, the tool, Daily huddle meetings (DHM), has only one feature (daily open meetings with workers on site). In this case, DHM is labeled as a Lean tool and also as a Lean technique.

3.5.1 Last Planner System

Alarcon and Calderon (2003) identified the Last Planner System (LPS) as one of the most effective tools in Lean Construction. It is a system of production control, introduced in 1992 by Glenn Ballard, that emphasises the relationship between scheduling and production control to improve flow of resources (Ballard 2000; Fewings 2013). The aim is to improve productivity by eliminating barriers to workflow (Ballard 1996). This is because a reliable workflow can help to achieve a simultaneous improvement in cost, quality, and safety as experience has shown that a considerable improvement in the flow of materials and information results in productivity improvement and waste reduction (Bertelsen 2004).

One of the main advantages of the Last Planner System is that it replaces optimistic planning with realistic planning by assessing the last planners' performance based on their ability to achieve their commitments (Salem *et. al,* 2005). Last planners are usually foremen or site supervisors who decide what work is to be done the following day (Song *et al.* 2008). They significantly influence the operational planning and production unit control. Operational planning involves designing the production structure in a way that will facilitate and improve the work flow while production unit control involves the completion of individual assignments at the operational level (Salem *et al*., 2005). Individual assignments in this context refer to works that are scheduled for the next day.

The LPS relies on *Should Can Will* analysis to develop a Weekly Work Plan as shown in Figure 3.1 (Ballard 2000; Song *et al.* 2008; Leading Answers 2011). Whilst “Should” indicates the work that is required to be carried out based on the schedule(s), “Can” indicates the work which can actually be carried out despite the various constraints on the site and “Will” indicates the works which will be carried out after all the constraints are considered (Salem *et al.,* 2005). In this case, the last planner makes commitments to doing what can possibly be done and not what should be done as illustrated in Figure 2.1. A master project plan is initially designed to provide information on all the work that should be done, however, constraints such as work sequence and availability of resources may sometimes put a limit to what can be accomplished. The LPS then empowers the last planners to propose a routine of production assignments based on the prevailing site conditions (Ballard and Howell 1998). Production assignments are scheduled based on the possibility of performing them and not based on what should be performed. Thus, the last planner makes commitment to the work that will be done (Song 2008).

Figure 3. 1 Last Planner System
Source: Leading Answers (2011)

In the Last Planner System, the efficiency of the production system in carrying out the assignments is determined by the ratio of the number of completed assignments to the total number of assignments committed in the week. This ratio is called the Percent Plan Completed (PPC). It is a measurement metric of the LPS showing the effectiveness of the production planning and the workflow reliability across the activities (Forbes and Ahmed 2011). The PPC is also calculated as the number of planned activities that are accomplished divided by the total number of planned activities (Ballard 2000). The production planning is said to be realiable when there is a positive (upward) slope between two PPC values. To achieve higher PPC values, additional Lean Construction tools such as First run studies could be further implemented in managing the project (Salem *et al*., 2005).

The LPS has three different planning levels; the master plan level; the six-week-look-ahead level; and weekly work plan level. At the master plan level, an effective production planning and control process is designed and incorporated into the master plan before construction works start. This is gradually updated, reviewed and detailed at both look-ahead planning and short-term levels (Saurin *et al.* 2002). The management selects appropriate construction methods and reschedules major tasks (Sacks *et al.* 2005). Work packages that could also cause delay or restrict access may also be rescheduled. At the Six-week look-ahead (SWLA) plan level, works to be carried out in the next one or two months are planned and renewed frequently (Forbes and Ahmed 2011). Constraints and hazards or risks related to work packages are minimised and eliminated where possible. Execution methods are also discussed to achieve a realistic plan. However, due to high uncertainty at this stage, the execution methods may not be thoroughly defined (Saurin *et al.* 2002). Finally, at the weekly work plan stage, works to be carried out the following week are assigned to different teams. Daily meetings could be held to re-evaluate weekly plans and redefine tasks (Saurin *et al.* 2002). This involves reassigning the tasks based on workers ability (Sacks *et al.* 2005; Sacks *et al.*, 2009). It is noteworthy that the Last Planner System has been successfully applied to control workflow unreliability on simple and complex construction projects (Abdelhamid 2002). According to the Lean Construction Institute reports, companies that applied the tool have successfully executed projects on time and within budget (Abdelhamid and Salem 2004).

3.5.2 Increased Visualisation

Increased visualisation is a Lean Construction tool that is used to effectively communicate certain vital information to the workers using signs and labels around the construction site (Fewings 2013). The tool is similar to Visual controls used in Lean manufacturing (Abdelhamid and Salem 2005). It makes operations and quality requirements clearer using charts, displayed schedules, painted designated inventory and tool locations (Salem *et. al.*, 2005). By frequently visualising these items, the workers are made to remember fundamentals such as workflow, schedules, quality requirements, performance targets, safety targets, and quality requirements among others. Furthermore, Pasquire and Connolly (2002) noted that displaying the performance indicators on site guides the workforce towards attaining the project target.

Increased visualisation was used by Walbridge Aldinger Construction Company in the United States where a project logistics plan was displayed to the subcontractors during the bid and throughout the construction process to address issues like site logistics, material scheduling, resources movement, waste management and site water management (Abdelhamid and Salem 2004). It saved lots of time and improved efficiency in transport, mater

However, signs, which are the most frequent application of this tool, have many shortcomings. These include possible misinterpretation, unsuitability for critical safety tasks, dependency on human interpretation and limited communication. Furthermore, they may be costly when used in large quantities (Saurin *et al.* 2006).

3.5.3 The 5S (House-keeping)

This is one of the foundations of Lean production management. It was developed from 5 Japanese words (Seiso, Seiton, Seiri, Seiketsu and Shitsuke). An attempt was initially made to translate the words while retaining the five S's (Sort, Straighten, Shine, Systemise and Sustain), however, the meanings slightly varied. Therefore, to get the actual meaning, the five words were rather translated as Cleanup, Arranging, Neatness, Discipline and Ongoing improvement (CANDO) (Bicheno 2000).

Bae and Kim (2007) consider 5S among the first steps an organisation should take in implementing Lean. The 5S process, also known as the Visual Workplace, makes the site conducive for the flow of value-adding activities by maintaining everything in its right place (Abdelhamid and Salem 2004). It makes orderliness and standardisation of operations to be the norm of an organisation and therefore helps towards eliminating waste of materials on construction sites. The 5S process reduces waste that could result due to overproduction, rework, variation or long cycle times (Narang and Abdelhamid 2006).

3.5.3.1 Seiso (Shine)

Seiso (shine) means to clean up (Salem *et al*., 2005). It involves removing all items from their unwanted places and clearing from the workplace other items that are not required within a given period such as inventories, plants, and other building materials (Bicheno; Fewings 2013). The presence of such items may result in a waste of working space and time, congestion and even accidents.

3.5.3.2 Seiton (Straighten)

Seiton (Straighten) means to neatly arrange tools and materials for ease of use (Abdelhamid and Salem 2005; Forbes and Ahmed 2011). it involves keeping the workplace orderly by placing all tools, plants and building materials in their optimal location (Bicheno 2000). The goal is to make the site convenient, safe and easy to work and to avoid double handling of items through effective arrangement.

3.5.3.3 Seiri (Sort)

Seiri (Sort) refers to separating the needed items and materials from the unneeded ones to achieve a neat and safer working environment (Salem *et al.*, 2005; Fewings 2013). By keeping everything at its right place, it is easier to detect inappropriateness. The time spent to search an item or locate a defect is also reduced.

3.5.3.4 Seiketsu (Standardise)

Seiketsu (standardise or Discipline) involves maintaining the first 3Ss above up to the standard that could aid in achieving a significant improvement in the operations (Abdelhamid and Salem 2005). The critical assumption here is based on the fact that it is easier to keep things going than to stop and restart all over again. It therefore maintains the mind setting in a state of established standard procedures and keeps the site in a “client’s visit” state all the time. It is quite difficult to achieve this at the beginning and may thus take several months to accomplish.

3.5.3.5 Shitsuke (Sustain)

Shitsuke (sustain) involves creating the habit of continuous improvement. It means maintaining a continuous improvement culture among the workforce, which is necessary as the work goes on under different conditions (Bicheno 2000). It could therefore be said that implementing the 5S lean tool has several benefits which include improved productivity and quality, set-up-times improvement, creation of space, reduced lead times, reduced cycle times, improved morale, and teamwork (Abdelhamid and Salem 2005). Furthermore, the tool has a direct impact on cost, quality and safe delivery of a project (Bicheno 2000). It makes working on the site easier and more convenient.

3.5.4 Error-Proofing (Poka-yoke)

Poka-yoke is a Japanese word for error-proofing (or fail-safing) which involves all the measures taken to minimise or prevent defects from occurring on site (Conner 2001). It is a way of avoiding inadvertent errors in a way that is simple and cost effective. It also involves all the necessary actions that prevent hazards from occurring as well as those measures taken to prevent the worker from getting in contact with the hazards. The concept relies on the creation of ideas that alert the occurrence of potential defects. According to Shingo, a defect occurs when a mistake reaches a customer and the aim of applying this tool is to prevent those mistakes from becoming defects (Bicheno 2000). In Lean manufacturing, Shingo introduced Poka-yoke (fail-safing) devices to prevent defective parts from flowing through the production process, with the concept relying on the creation of ideas that alert the occurrence of a potential defects (Salem *et al.*, 2005). In Lean Construction, fail-safing activities include visual inspection, risk assessment and analysis and any other action that prevents bad outcomes through mistakes. The use of error-proofing (or fail-safing) devices is key to maintaining improvements in an organisation (Pasquire and Connoly 2002).

The benefits realised from successful application of this tool in construction projects in Denmark and the United States includes reducing variability and improving work reliability (Abdulhamid and Salem 2004; Bertelsen, 2004 and Conner 2001). However, a US based Lean contractor suggested that the top management commitment is vital to its successful implementation (Abdelhamid and Salem 2004).

3.5.5 The 5 Whys

The five times repetition of "why" (5 whys) when confronted with a problem helps to uncover the root cause of the problem (Nicholas 1998). The Toyota production system is built on the practice and evolution of this scientific approach. The name originated from the fact that "why" needs to be asked at least five times to trace the root cause of a problem (Bicheno 2000). The tool simply requires the workforce and the management to ask "why?" over and over when a problem occurs. By doing this, the initial cause of the problem could be traced until all defects are exposed and addressed to prevent reoccurrence. For instance, by tracing the root of a problem to the design, all the necessary corrections could be made and the quality of the design will therefore be improved. It is believed that the tool has given the Japanese motor industry an edge on quality, reliability and productivity.

3.5.6 Daily Huddle Meetings (DHM)

This is a Lean Construction tool where a brief daily start-up meeting is conducted to collect reports on the state of the work since the previous meeting. It is an avenue where reports are made on work progress, issues affecting work progress and safety. The tool ensures a rapid response to problems through continuous open communication and workers empowerment. The meeting with workers is a two-way communication between the team and its leader, with the workers being directly involved in problem solving to inspire them, maximise productivity and increase job satisfaction (Salem *et al*., 2005).

3.5.7 First Run Studies

In order to achieve continuous improvement in the production process, First Run Studies are used to plan out and improve crucial assignments. The tool involves studying a task or an assignment to be carried out, reviewing the alternative work methods, and identifying and reorganising the different functions involved in executing the assignment, with the best and simplest approach being illustrated to the workers using video files, pictures, or graphical representations (Abdelhamid and Salem 2004). The first run of a selected assignment is critically examined in detail considering alternative ways of executing the task. The tool uses a Plan-Do-Check-Act (PDCA) cycle to lean the process (Forbes and Ahmed 2011). Here, “Plan” involves selecting the operation to study, bringing together the workers or specialists involved, studying the steps to differentiate value and non-value adding steps, thinking of ways to eliminate the non-value adding steps, and then checking for strategies to ensure safety and quality improvement (Salem *et al.*, 2006). “Do” involves testing the ideas on the first run whilst “Check” involves describing and measuring what really happens. The “Act” stage involves reassembling the team, and discussing the improved method and performance as the standard expected of the team to meet (Abdelhamid and Salem 2004).

3.6 Lean Construction Practice in the United Kingdom

Construction is one of the key areas that support the UK's economy (ONS 2011). In an attempt to improve performance and efficiency in the construction industry, a construction task force was set up in 1998 by the Deputy Prime Minister under the chairmanship of Sir John Egan to bring up a proposal that will ensure continuous and sustainable improvement in construction project quality and customer satisfaction. The task force was also saddled with the responsibility of advising the government on strategies that will reduce waste production throughout the construction process (Egan 1998). To achieve a significant reduction in capital cost, construction time and defects and in order to significantly improve productivity, process reliability, predictability and profits, the task force as part of its proposal, recommended the application of Lean production principles in the project delivery processes in the construction sector (Egan 1998). The Construction Lean Improvement Programme (CLIP) was established in 2003 under the Building Research Establishment (BRE) to support the UK construction industry in implementing Lean Construction to improve client's satisfaction, efficiency, profits and productivity (CLIP 2012). It also provides guidance to contractors and consultants applying Lean techniques in delivering construction projects (Fewings 2013).

Through the adoption and application of the Lean approach and concepts, the UK construction companies were able to achieve a significant reduction of time for executing the project by forecasting the occurrence of certain problems and developing strategies for addressing them ahead of their occurrence (Suresh *et al.,* 2012). The approach has also drastically contributed towards improving staff morale, productivity, cost savings to both the client and the contractor and promotion of innovative ideas. Furthermore, it helped to improve the relationship between the contractor and the client as well as among the workforce and enabled the company to develop certain work strategies and culture which they could adopt in future projects (Bashir 2009; CLIP 2012).

3.7 Challenges facing Lean Construction Practice

Several researches have been conducted in various countries to identify the challenges that could affect the successful implementation of Lean Construction. Based on a thorough and critical review of literature relating to the take up of Lean Construction practice, the research classified these challenges into six categories. These are:

1. Management-related issues;
2. Financial issues;
3. Educational issues;
4. Attitudinal issues;
5. Government related issues; and
6. Technical issues.

3.7.1 Management- related Issues

The top management of every organisation has a major role to play in achieving a successful implementation of innovative strategies (Salem *et al.,* 2005; Hudson 2007). The success of lean practice lies in their commitment in developing and implementing an effective plan and adequately providing the required resources and support to manage changes arising from the implementation. However, some challenges identified in several studies are related to management issues. Such studies include Olatunji (2008) which found poor project definition, inadequate resources and delay in materials delivery. Furthermore, Mossman (2009) identified lack of time for innovation while Alarcon *et al.* (2002) and Abdullah *et al.* (2009) found long period of implementation as the challenge in some organisations. In addition, Polat and Ardit (2005), Alinaitwe (2009) and Forbes and Ahmed (2004) identified poor communication while Alinaitwe (2009) found lack of client, subcontractor and supplier involvement and lack of transparency. On the other hand, Koskela (1999) identified inaccurate preplanning. Similarly, Common *et al.*, (2004) and Forbes and Ahmed (2004) found additional challenges that include delay in decision making, unsuitable organisational structure, weak administration and poor procurement selection strategies. Though some of the challenges appear easy to be addressed, overcoming them is crucial to smooth Lean Construction practice across organisations.

3.7.2 Financial Issues

The implementation of innovative strategies like Lean Construction requires some funds. Adequate funding is needed to motivate the workers, provide relevant materials and equipment, and in some cases employ lean specialist or consultant to guide both employers and employees in implementing the concept. Finance related issues are among the most common challenges to lean practice across different organisations in various countries but the nature of this barrier varies across countries. Olatunji (2008) identified poor professional wages, corruption and lack of incentives and motivation while Mossman (2009) found risk aversion. Furthermore, Common *et al.,* (2000) identified some of the financial challenges to include inflation and implementation cost. Unless adequate efforts are made to overcome these challenges, several companies could be discouraged from implementing lean in their organisations.

3.7.3 Educational Issues

There have been several efforts to provide awareness, guidance and knowledge relating to Lean Construction by academics, researchers, practitioners and bodies such as Lean Construction Institutes (LCI), Construction Lean Implementation Programme (CLIP), Construction Excellence (CE) and British Research Establishment (BRE). However, these bodies operate in very few countries. Despite the large amount of publications made by researchers, it seems educational issues appear to be the most common challenges to lean practice. This may be related to the fact that the concept was adopted from the manufacturing industry. Existing studies such as Olatunji (2008) found illiteracy/inadequate knowledge among workers while Alarcon *et al.,* (2002) found lack of training and lack of information sharing. Furthermore, Abdullah *et al.,* (2009) found difficulty in understanding concepts, and inadequate exposure to the need for lean implementation. Also, Common *et al.,* (2000), Castka *et al.,* (2004), Jorgensen and Emmitt (2008) identified lack of awareness programmes. Hence, it can be suggested that educational challenges pose a great threat to the sustainability of lean practice.

3.7.4 Governmental- related Issues

Despite the significant economic contribution made by the construction sector in various countries, it faces numerous problems which appear to be related to government policies. Some studies reveal that certain challenges to Lean practice arose due to government attitudes towards the construction industry in some countries. According to Olatunji (2008) and Alinaitwe (2009), challenges like inconsistency in policies and unsteady price of commodities impede the implementation of Lean Construction in some countries.

3.7.5 Technical Issues

The implementation of Lean Construction may be affected by challenges which are technical. These challenges are considered technical because they have a direct impact on applying certain Lean Construction principle and tools such as reliability, simplicity, flexibility and benchmarking (Koskela 1992). Design related challenges to Lean Construction identified in existing studies include incomplete designs, inaccurate designs and lack of design constructability (Koskela, 1999; Ballard and Howell, 1998; Alinaitwe, 2009). Furthermore, Polat and Ardit (2005) identified uncertainty in supply chain while Alinaitwe (2009) found poor performance measurement strategies. The aforementioned technical issues, if not addressed, could hinder wholistic implementation of Lean Construction. A haphazard implementation of lean may not yield full benefit of the concept in construction.

3.7.6 Human Attitudinal Issues

According to Howell (1999), human attitude is one of the major factors affecting the implementation of Lean Construction in various construction industries. According to the studies carried out by Common *et al.,* (2000), Cua *et al.,* (2001), Castka *et al.,* (2004), Bechdol *et al.* (1995), Forbes and Ahmed (2004), some of the attitude related factors are lack of cooperation, poor leadership, poor understanding of client's brief, misconceptions about lean practice and lack of committed leadership. Furthermore, other research studies such as Olatunji (2008), Alarcon *et al.* (2002), Alinaitwe (2009) and Mossman (2009) identified lack of teamwork, lack of self-criticism, poor house-keeping and fear of unfamiliar practices as some of the attitudinal challenges to Lean Construction.

3.8 Integrating Lean Construction Practice and Safety

The principles of Lean thinking emphasise on delivering value to the client while continuously improving the production process to eliminate non-value adding activities and any interruption to the flow of value, which are collectively considered as waste. Lean Construction practice sees any incident that affects workers comfort and hinders the flow of value-adding activities to the client as a potential waste that needs to be eliminated. Accidents result in several wastes in the form of decreased productivity, reduced human resource efficiency, waste of financial resources and time, among others. Therefore, to achieve a reliable and uninterrupted workflow, accident is a potential waste that has to be eliminated. The prevention of occupational accidents could prevent the waste of productive hours and compensation costs which could otherwise add to overall project cost and duration (Sacks *et al*. 2005; Jang and Kim 2007).

However, several critical observers of lean production suggest that the system has a poor approach to human resource management (Green 2001), with suggestions from studies by Fucini and Fucini (1990), Garrahan and Steward (1992) Rehder (1994) and Turnbull (1998) associating the system with excessive stress on and exploitation of workers, unnecessary surveillance and exposure workers to poor safety standards. Furthermore, according to Rehder (1994) and Green (1999), the system has resulted in traffic congestion and environmental pollution in the manufacturing sector.

Whilst Howell and Ballard (1999) argued that lean is a step toward accident reduction on construction sites, studies by Thomassen *et al.* (2003), Saurin *et al.* (2004), Saurin *et al.* (2006) and Mitropoulous *et al.* (2007) suggest that the application of Lean Construction tools could improve safety on construction sites. To enhance an understanding of this link between Lean Construction tools and techniques, on one hand, and reduction of accidents on construction sites, on the other hand, a detailed discussion of the influence of the individual tools and their techniques on reduction in construction accidents is imperative.

3.8.1 Last Planner System (LPS):

Last planners are usually foremen or site supervisors who are empowered to decide what work is to be done the following day on site (Song *et al.,* 2008). In line with this and based on their expertise and abilities, they develop a weekly plan of work to be carried out on site (Ballard 2000; Song *et al.,* 2008). This concept could contribute to a reduction in problems like excessive stress and organisational pressure which are considered to be among causes of accidents on site (Suraji *et al.,* 2001; Loughborough and UMIST 2003; Haslam *et al.,* 2005; FISCA 2006).

According to studies conducted by Garrahan and Steward (1992) and Green (2001), the lean production system exposed workers to excessive stress, exploitation and very high working hours. Kamata (1982) and Fucini and Fucini (1990) also pointed out that the system deprives workers of freedom. However, the Last Planner System indicates that adopting Lean Construction rather empowers workers to engage in tasks and methods that correlate with their abilities.

The LPS emphasises on planning and controlling the construction process at both monthly and weekly levels. This could help to reduce risks and hazards which occur due to poor planning and control (Nahmens and Ikuma 2009). At the planning stages, the different risks and hazards are identified and effective decisions are taken on how to manage them. At the master plan stage, safety could be improved by selecting appropriate construction methods and planning for safety equipment (Sacks *et al.* 2005). The management correlates workers ability and the work methods, make provision for safety equipment, and develop a schedule of tasks based on workers' ability (Sacks *et al.,* 2005). This minimises accidents caused by poor work methods, workers' inability and inadequate safety equipment. At the six-week look ahead stage, works to be carried out in the next one or two months are planned, with safety supervisors developing a plan for supervision schedules to avoid accidents due to poor supervision (Sacks *et al.,* 2005). Furthermore, the Pre-task hazard analysis (PHA) is carried out to identify and reduce or eliminate risks and hazards (Howell *et al.,* 2002; Saurin *et al.,* 2002). At the weekly work plan stage, the work to be carried out the following week is planned and assigned to different workers based on their ability and commitments (Sacks *et al.,* 2005; Sacks *et al.,* 2009). The project managers and site supervisors identify activities with potential risk and carry out the necessary adjustments to protect the workers and ensure safety. Should any hazard be identified at the time an assignment is being carried out, the root cause and the planning are investigated so that the necessary action is taken to avoid recurrence (Howell *et al.,* 2002).

According to Fucini and Fucini (1990), the lean production system exposed workers to poor safety standards. However, it could be argued that the safety measures planned across these three planning stages indicates that safety is an integral part of Lean Construction practice.
According to Rasmussen *et al.,* (1994), organisational pressure pushes workers to engage themselves in works that are beyond their ability and skills, which subsequently causes accidents on site. Therefore, the application of LPS could reduce the likelihood of accidents occurrence by correlating workers' skills with the tasks demands in planning the production process (Saurin *et al.,* 2006; Mitropoulos *et al.,* 2007). Furthermore, the involvement of

workers in production planning and correlating construction methods with their skills and ability could reduce accidents caused by physical and mental disability and excessive stress. However, despite the relevance of the Last Planner System to safety, there is no empirical evidence that its application promotes safety in construction.

3.8.2 Increased Visualisation

Ensuring visibility could promote safety by making the site more convenient and safer for the workers (Salem *et al.,* 2007). Saurin *et al.,* (2005) and Fewings (2013) identified visual management as one of the key principles of promoting safety on the construction site. Visual management could be used to communicate vital information to workers with low levels of literacy, knowledge and poor site awareness to reduce the likelihood of accidents occurring. According to Sawacha *et al.* (1999), FISCA (2006), Tyler and Lamont (2008) and Donaghy (2009), poor communication, low level of knowledge and poor site awareness are among the key causes of accidents on construction sites. Similarly, Kletz (1993), Sawacha *et al.* (1999), Suraji *et al.* (2001), Howell *et al.* (2002) and FISCA (2006) pointed out that some accidents occur on site as a result of poor workplace organisation and failure to see materials and objects placed at wrong locations. Increased visualisation could be used to overcome these kinds of problems because ensuring visibility helps to reduce accidents caused by slipping, tripping and falls which are among the key causes of accidents on site (Hughes and Ferrrett 2008).

Visual devices such as safety signs, visual demarcations, and borders on floor could significantly contribute in promoting safety by providing information that enables workers to identify safe boundaries, hazards and risks (Saurin *et al.* 2006). Workers' ability to identify workstations and pathways easily assists in reducing chances of errors and mistakes which could lead to accidents (Sacks *et al.* 2009). The boundary beyond which work is no longer safe should be made very visible to the workers so that the boundaries would neither be crossed nor be too closely approached (Mitropoulos *et al.* 2003 and Saurin *et al.,* 2005). Therefore, it could also be used to reduce workers' exposure to chemical hazards (Nahmens and Ikuma 2009). Visualisation tools could also facilitate communication to the workers and help safety supervisors in improving control among the workers. This could potentially reduce accidents caused by poor communication.

Though poor visualisation is a common cause of accident, human errors and poor judgment errors also constitute a major cause of accidents which could be reduced in a transparent and visible working environment (Sacks *et al.,* 2009). Though studies conducted by Fucini and Fucini (1990), Garrahan and Stewart (1992) Turnbull (1988) report that lean production concepts expose workers to poor safety environments, it seems the application of this concept could rather reduce workers exposure to unsafe situations. However, it could be argued that when used in large quantities, these signs could be distractive, thereby impacting negatively on safety by increasing the chances of accidents occurring on site. Moreover, due to the dynamic and diverse nature of construction sites, it is difficult to use visual devices to interprete the different forms of hazards. In fact, hazards such as fatigue and team interference are not visible and as such cannot be interpreted. In addition, data on safety performance may be difficult to collect and interprete on the visual devices (Saurin *et al.* 2006). This tool may also need to be used in conjunction with other tools to effectively improve safety (Nahmens and Ikuma 2009).

3.8.3 The 5S (House-keeping)

Like the previously discussed Lean Construction tools, the 5S (house-keeping) tool comprising of seiso, seiton, seiri, seiketsu and shitsuke seems to have a potential for reducing accidents on construction sites. According to Sawacha *et al.* (1999), Suraji *et al.* (2001), Haslam *et al.* (2005) and FISCA (2006), a poorly organised workplace is one of the major causes of accidents on site. In addressing this, the tool in general emphasises a systematic achievement of an organised, standardised and clean work environment. Seiso suggests that materials/ items and machines which are not needed for use immediately should be retired from sites (Bicheno 2000). As applied to accidents, this Lean Construction technique ensures prevention of congestion and obstruction from machines and materials that are not required on sites for the time being. To the extent that obstruction and congestion on construction sites are well known accidents drivers (Howell *et al*., 2002; HSE 2009), their avoidance is critical to accident reduction on construction sites.

Closely aligned to Seiso is Seiton, which requires the placement of plant and materials at their optimum location to ease identification and promote orderliness at the workplace (Abdelhamid and Salem 2004). In the context of construction sites, this means that plant and materials must be located at where they are mostly needed such that access to them will not be embroiled in unnecessary movements, circulation and congestion to avoid accidents.

As applied to construction sites, Seiri suggest that construction sites should be cleared of unwanted materials to allow free flow of materials, circulation and above all ensure safer movements. This could reduce chances for trips, falls and exposure to hazards which could result in accidents and affect the production process (Salem *et al.* 2007; Nahmens and Ikuma 2009). Seiketsu conversely emphasises the maintenance, cleanliness and orderliness on production sites. This suggests that construction sites should demonstrate clean and orderly environment for the purpose of safety and maximum performance (Abdelhamid and Salem 2005). This could address poor safety culture among workers on construction sites, which is a determinant of accident (Sawacha *et al* 1999; Toole 2002). This is reinforced by Shitsuke, which emphasises the continuous improvement in safety culture among workforce on construction sites (Bicheno 2000). Keeping the internal and external parts of the site clean and visible could also make the site more hygienic and reduce chances for accidents to occur.

Whereas studies carried out by Fucini and Fucini (1990), Green (1999) and Rehder (1994) have associated the lean production system with traffic congestion, environmental pollution and exposure of workers to poor safety standards, it appears that the application of the 5S could help to reduce workers exposure to such issues (Narang and Abdelhamid, 2006 and Bae and Kim, 2007). Hence, the tool could potentially reduce chances for accidents to occur on sites though there is no empirical evidence to support this assertion as well.

3.8.4 Error-Proofing

Studies such as Suraji *et al*., (2001), Fang *et al*., (2004) and Katsakiori *et al*., (2009) have established that human errors particularly errors of judgement among workers is one significant determinant of accident on construction sites. Given that error-proofing concentrates on all the techniques that can prevent accidents in a production system, such techniques to a large extent could contribute to reduction of accidents on construction sites. These techniques entail visual inspection, risk analysis and assessment, introduction of error-proofing devices such as gadgets to raise alarms of errors and shut down operating machines automatically upon detection of errors. Devices which automatically shut down or raise alarms could be used to prevent the workers from coming too close to or crossing the boundary for unsafe conditions (Saurin *et al.* 2005). The implication of the foregoing is that upon application of such Lean techniques, the propensity of accidents occurring can be anticipated and averted. To promote safety, error-proofing devices could be used to prevent the occurrence of errors rather than protecting workers in the aftermath (Saurin *et al.* 2006). Even where errors or accidents occur, the techniques will prevent or minimise their impact. For example, the use of safeguards and personal protective devices minimise the impacts of falling objects, a recipe of accidents on construction sites (Hughes and Ferrett 2008). Similarly, such devices could also protect workers from site hazards like excess heat, noise and dust, among others (Saurin *et al.*, 2006).

3.8.5 Daily Huddle Meetings (DHM)

Meetings are part of continuous improvement opportunities that could be used to identify and reduce safety hazards on construction sites. They are held on site to review how to handle and use machines and plants to avoid exposing the workers to risk. Monthly meetings may also be held to evaluate safety performance of the company (Saurin *et al.* 2002). The meetings also identify and discuss project hazards and deliberate on accident reports (Howell *et al.* 2002). Other safety related issues that could be discussed include workloads, emergency procedures, environmental risks, safety performance indicators, social relationships with colleagues and managers, personal protective equipment, and material handling, among others.

During meeting workers and managers satisfaction with safety plans are evaluated, workers being encouraged to discuss the good and bad aspects of their tasks and empowered to suggest ways of solving different problems identified (Saurin *et al.* 2002). A major advantage of the meeting is it gives avenues for identifying new risks as well as evaluating effectiveness of existing strategies in handling the risks. It also gives room for enlightening and educating the workers, which is vital to promoting safety (Egbu 1997; Anumba *et al.*, 2004). An action plan may be developed during meetings on how certain strategies could be implemented (Saurin *et al.* 2002). However, there is no empirical evidence that shows that these meetings improve safety on site.

As noted in Table 2.1, poor communication and coordination are major sources of accidents on construction sites (Wolf and Brick 1996; Anumba *et al.*, 2004; FISCA 2006; Hughes and Ferrett 2008). DHM emphasises regular and continuous interaction among workers, supervisors and site managers. By this practice, it is expected that routes for communication and discussions will be opened on construction sites in connection with execution of work and its associated risks. As such, prior steps could be taken to avoid accidents.

3.8.6 The 5 Whys

Razuri *et al.* (2007) identified incident investigation as a key technique in safety management. The tool could enable safety managers to investigate the root cause of an accident on construction sites (Howell *et al.* 2002). It also gives a lot of information on how accidents occur as well as ways of avoiding them. Moreso, the tool could be used to determine whether the accident occurred as a result of a wrong execution of a proper intention or it is due to the correct execution of a wrong intention (Howell *et al.* 2002). Furthermore, Ng *et al.,* (2010) suggest that the tool could help to reduce the possibility of the accident to reoccur.

3.8.7 First Run Studies (FRS)

Due to the diverse and complex nature of construction activities, some tasks demand highly skilled workers and complicated work methods. FRS is a lean tool that is used to map out strategies for accomplishing a critical task (Salem *et al.,* 2005). Critical task planning involves studying the task, reviewing different work methods to identify the most appropriate method that matches the workers ability and convenience. This minimises exposure to risk and poor work methods which are among the causes of accidents on site identified by Nishishima (1989) and Suraji *et al.* (2001). The tool enables the project manager to redesign critical activities that could otherwise expose workers to high risks and hazards (Howell *et al.,* 2002). First Run Studies could be used to minimise chances for errors to occur (Mitropoulos *et al.* 2003).

To further minimise chances for accidents caused by human errors and judgement errors to occur especially among workers with low levels of knowledge and poor site awareness, the selected approach is illustrated using video files, pictures and other graphical illustrations (Abdelhamid and Salem 2004). Research conducted by Bellamy and Geyer (1992), Wolf and Brick (1996), Suraji *et al.,* (2001), FISCA (2006) and Hughes and Ferrett (2008) identified poor planning of site operations among key causes of accidents on sites. The application of this tool could therefore reduce the likelihood of accidents caused by these problems to occur. However, this needs some empirical evidence to be established.

From the above critical analysis of the relevance of Lean Construction tools in addressing onsite causes of accidents, a potential relationship can be summarised in Table 3.2 below. The table shows the major onsite causes of accidents identified by various studies and the tools considered to be relevant in minimising particular causes of accidents. This provides a guide to further investigate the relevance of Lean to safety.

However, to be more precise the following areas were specifically identified as points of potential inter-relationship between Lean Construction tools and onsite causes of accidents.

Last Planner System

1. Correlating work methods with workers' skills could potentially reduce accidents which could result due to excessive stress (Mitropoulos *et al*., 2007).
2. Workers' empowerment in assignment scheduling could potentially reduce accidents caused by organisational pressure (Howell *et al*., 2002).
3. Pre-task hazard analysis could help in risk identification and reduction (Howell *et al*., 2002; Saurin *et al*., 2002).
4. Logically, correlating work methods with workers' ability could potentially reduce accidents caused by physical and mental inability.

Table 3. 2 Lean tools and relevant onsite causes of accidents

Lean Construction Tools	Lean Techniques	Relevant Onsite Causes of Accident
Last Planner System	Workers' empowerment, correlation of work methods with workers' skills, correlation of tasks with workers' ability, pretask hazard analysis, workers' involvement, weekly work planning, supervision plan.	Poor work methods, Excessive stress, Poor supervision, Poor planning and control, Poor coordination of workers and simultaneous activities, Physical and mental inability, Organisational pressure
5S (House-keeping)	Clean workplace, improved ergonomics, materials and plants' organisation, workplace organisation, site neatness, and easy movement, circulation	Site congestion, Poor working environment, Site hazards (dust, noise etc), Trips and slips, working in confined space, working at height, falling objects
Increased Visualisation	Safety signs and labels, visual safety demarcations, visual safety borders and visibility improvement	Poor communication, poor planning and control, lack of site awareness, lack of knowledge, violation of regulations, judgement error
First Run Studies	Critical tasks planning, construction methods review, work methods illustration and risk minimisation	Poor work methods, lack of knowledge, Judgement error, lack of motivation, human error, procedural issues
Daily Huddle Meetings	Open communication, coordination of workers and simultaneous activities, workers' empowerment, workers' involvement, information sharing and safety planning	Poor communication, poor coordination of workers, lack of site awareness, poor coordination of simultaneous activities, lack of motivation
Error-proofing (Poka-yoke)	Visual inspection, personal protective devices, hazards warning and alert systems, equipment failure alert	Judgement error, Human error, Equipment failure, Falling objects

5. Logically, the coordination of workers and simultaneous activities could potentially reduce site congestion which is a major cause of accidents on site.
6. Logically, workers' empowerment in assignment scheduling could potentially reduce accidents caused by excessive stress.
7. Logically, weekly work planning could potentially reduce accidents caused by poor planning.

Increased Visualisation

1. Safety signs and labels could potentially reduce accidents caused by human error (Saurin *et al*., 2005, 2006).
2. Visual safety borders and demarcations could potentially reduce accidents caused by human error (Saurin *et al*., 2004, 2005; Mitropolous *et al*., 2003).

3. Visibility improvement could potentially reduce accidents caused by tripping (Nahmens and Ikuma 2009).
4. Logically, Safety signs and labels could potentially reduce accidents caused by poor communication.
5. Logically, visibility improvement could potentially reduce accidents caused by human error.

Daily Huddle Meetings

1. Workers involvement in daily huddle meetings (DHM) could potentially reduce accidents caused by poor communication (Saurin *et al*., 2002).
2. Workers involvement in daily huddle meetings (DHM) could help in risk identification and reduction (Saurin *et al*., 2002).
3. Workers involvement in daily huddle meetings (DHM) could potentially reduce accidents caused by lack of safety awareness (Saurin *et al*., 2004).

First Run Studies

1. Critical task planning could potentially reduce accidents caused by poor planning and human error (Mitropoulos *et al*., 2007).
2. Logically, work methods illustration could potentially reduce accidents caused by lack of knowledge to read work statements and non-compliance with procedures.

Error-proofing

1. Logically, visual inspection could potentially reduce accidents caused by poor supervision.

5S

1. Clean workplace could potentially reduce accidents caused by site hazards like dust (Nahmens and Ikuma 2009).
2. Logically, the cleaning of workplaces could potentially reduce accidents caused by untidiness on site.
3. Logically, materials and plant organisation could potentially reduce accidents caused by site congestion.
4. Logically, materials and plant organisation could potentially reduce accidents caused by falling objects.

Table 3. 3 Lean techniques relevant to onsite causes of accidents

Safety issue/ Onsite Causes of Accidents	**Relevant Lean Construction Techniques**	**Lean Construction tool**
Poor planning and control	Weekly work planning	Last Planner System
	critical task planning	First run studies
Site congestion	Coordinating workers and simultaneous activities	Last Planner System
	Materials and plants organization	5S (House-keeping)
Lack of site awareness	Daily huddle meetings	Daily huddle meetings
Excessive stress	Workers empowerment in assignment scheduling	Last Planner System
	correlating work methods with workers' skills	Last Planner System
Lack of knowledge to read work statements	Work methods illustration	First run studies
Non-compliance with procedures		First run studies
Human/ Judgement error	Safety signs and labels	Increased visualisation
	Visibility improvement	Increased visualisation
	Visual safety borders and demarcation	Increased visualisation
Poor supervision	Visual inspection	Error-proofing
Poor communication	Workers' involvement in DH meetings	Daily huddle meetings
	Safety signs and labels	Increased visualisation
Physical and mental inability	correlating tasks with workers' ability	Last Planner System
Untidy site	Clean workplace	5S (House-keeping)
Site hazard (eg dust, noise)	Clean workplace	5S (House-keeping)
Falling objects	Materials and plants organization	5S (House-keeping)
Organisational pressure	workers empowerment in assignment scheduling	Last Planner System
Tripping	Visibility improvement	Increased visualisation
Risk identification and reduction	Pre-task hazard analysis	Last Planner System
	Daily huddle meetings	Daily huddle meetings

Table 3.3 could now be developed into an interaction matrix to demonstrate more clearly the potential relationships between the safety antecedents and Lean Construction techniques. The matrix shows areas of potential interaction between Lean Construction techniques, onsite causes of accidents and some other safety issues. The potential interactions are shown by the point of intersection of these factors. Across the table are the Lean techniques labeled L1-L15 while down the table are the safety issues labeled S1-S16. A large number of the safety issues are causes of accidents on construction site. For example, from the matrix, "worker's empowerment in assignment scheduling" could be used to reduce accidents caused by excessive stress and organisational pressure. Similarly, "cleaning the workplace" could potentially reduce accidents caused by "site hazards". The interactions labeled R^1 are based on logical conclusions while the interactions labeled R are relationships suggested by previous studies which, however, lack empirical evidence.

Table 3. 4 Possible Interaction Matrix of Lean Construction Techniques and Safety issues

	LPS techniques					Daily Huddle Meetings		First Run Studies		Increased Visualisation			EP	5S (House-keeping)	
	Workers' empowerment in assignment scheduling	Correlating work methods with workers' skills	Correlating tasks with workers' sability	Pre-task hazard analysis	Weekly work planning	Coordinating and workers simultaneous activities	Daily huddle meetings	Critical tasks planning	Work methods' illustration	Safety signs and labels	Visual safety borders and demarcations	Visibility improvement	Visual inspection	Clean workplace	Material and plants' organisation
Safety issues/ Onsite accident causations	L1	L2	L3	L4	L5	L6	L7	L8	L9	L10	L11	L12	L13	L14	L15
S1. Tripping												R			
S2. Excessive stress	R^1	R													
S3. Poor supervision													R^1		
S4. Poor planning					R^1			R							
S5. Falling objects															R^1
S6. Organisational pressure	R														
S7. Poor communication							R			R^1					
S8. Site hazards (eg dust, noise)														R	
S9. Human/ Judgement error										R	R	R^1			
S10. Risk identificatn & reduction				R			R								
S11. Lack of knowledge									R^1						
S12. Lack of safety awareness							R								
S13. Physical and mental inability			R^1												
S14. Site congestion						R^1									R^1
S15. Untidy site														R^1	
S16. Procedural issues									R^1						

R^1- 12 Potential relationships identified based on logical analysis

R - 11 Potential relationships identified in past studies lacking empirical evidence

3.9 Development of a Conceptual Framework

The aim of the framework is to guide both companies applying Lean Construction and those intending to apply Lean on how they could use the techniques to promote safety on construction sites. The framework represents a conceptualisation of how the different parts relate with one another in achieving the desired outcome, which is to promote safety. However, to achieve this ***desired outcome***, the organisation has to ***put in*** something (input) into its system, which is then engaged in some ***processes*** to achieve the desired outcome. In doing so, the system may encounter some ***challenges*** that need to be addressed using certain ***strategies*** so that the desired outcome can be achieved. Some measures may also have to be undertaken to avoid or address any ***negative impact*** that may be associated with the processes.

Therefore, the framework comprises of the following sections: the input; processes; challenges; strategies for overcoming the challenges; negative impacts; strategies for avoiding or addressing the negative impacts; and positive outcomes. These components are further discussed below.

3.9.1 Input

An input is something the organisation put into its system to achieve some targeted results. It is therefore what is required of the organisation to do in order to improve safety on its project sites. In this case, the input is to engage in the wholistic application of Lean thinking in its entire project delivery processes. Lean Construction practice does not begin with applying Lean Construction techniques. Rather, it commences with imbibing of Lean principles. The organisation has to first ensure that its staff understand and apply the Lean principles. The application of these principles is, thus, the main input in the road map to adoption of Lean thinking.

3.9.2 Processes

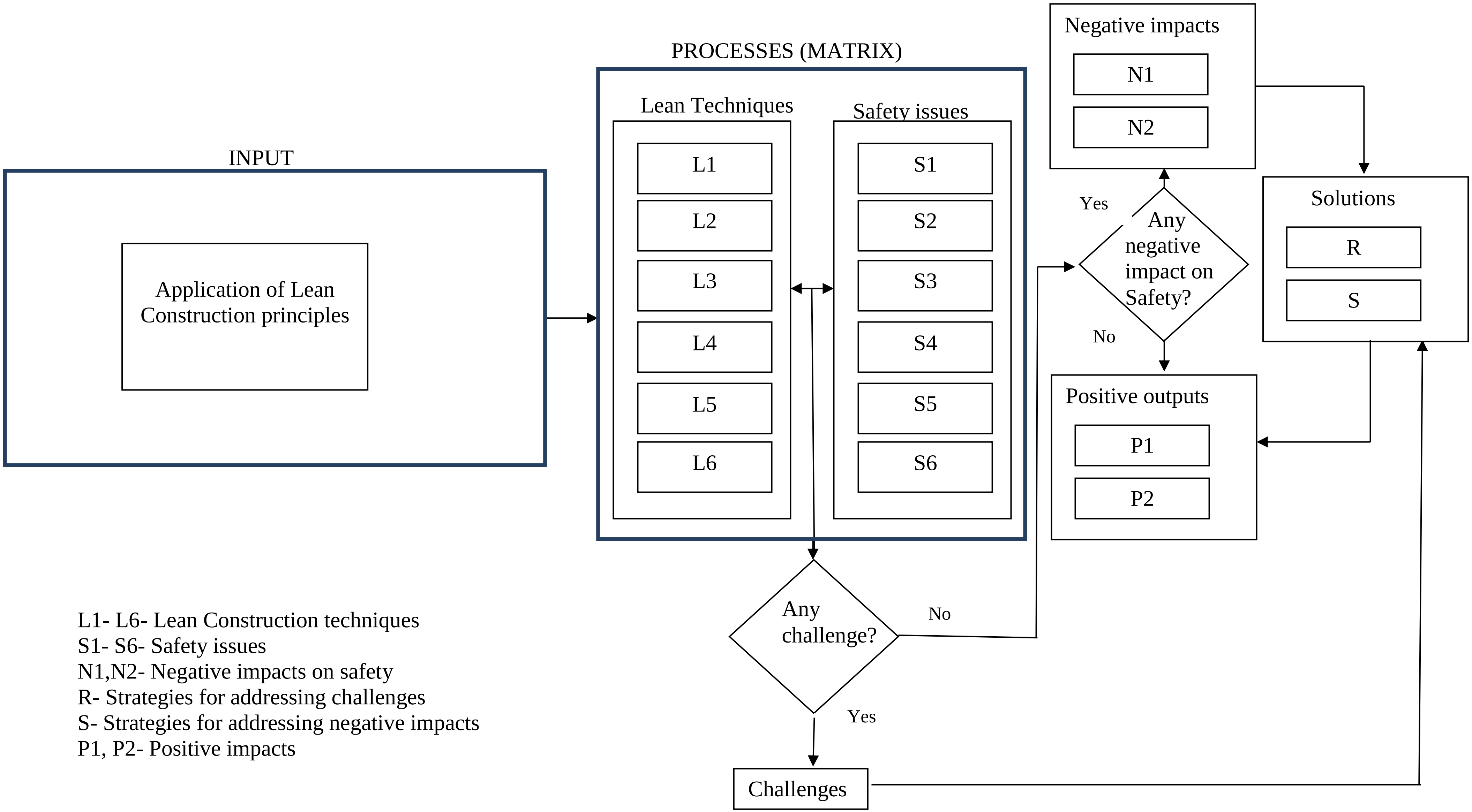
Subsequent to the application of Lean principles, the organisation undergoes certain Processes. These processes involve applying the appropriate Lean Construction techniques to address the relevant safety issue confronting the organisation. The selection and application of a Lean Construction technique is determined by what an organisation wants to achieve. In order to improve safety, which is the primary driver in this case, the organisation has to identify which Lean Construction tool or techniques can be used to address certain form of safety issue. Based on the literature reviewed, a number of interrelationships have been identified between safety issues and Lean techniques from logical analysis and past studies. These relationships are compiled in the interaction matrix shown in Table 3.3. In this case, the Processes involve applying the Lean Construction techniques identified in the matrix to address the relevant safety issue as shown in the matrix. Therefore, the interaction matrix is a full detail of the "Processes" component of the framework, showing which kind of Lean technique (L1-L15) could be used to promote safety by reducing what sort of risks, hazards, or a particular cause of accident (S1-16). The safety issue to be addressed therefore determines which Lean technique(s) is selected and applied. Similarly, an organisation could proactively apply a Lean technique in order to achieve its safety benefit(s). However, these relationships lack adequate empirical evidence. Therefore, it becomes necessary to validate these relationships based on adequeate empirical evidence and further explore other ways Lean Construction techniques could be used to promote safety.

3.9.3 Challenges

The application of Lean Construction techniques are usually confronted with challenges of different nature as discussed in Section 3.7. These include lack of Lean knowledge, inadequate funding, poor management, unfavourable government policies and risk aversion among others. Though these are challenges facing Lean Construction practice across different countries, contact with the UK contracting organisations would help in identifying certain challenges peculiar to them. This could help in making the framework more robust.

3.9.4 Strategies for addressing the Challenges

These are the different ways of addressing the challenges to Lean Construction practice. The challenges have to be addressed in order to realise the targeted benefits. This section of the framework presents strategies that could be used in overcoming the challenges. In an attempt to identify ways of addressing these challenges, Suresh *et al.,* (2012) identified creation of Lean awareness programs, staff training and education on Lean techniques, and government policies. There seems to be inadequate strategies reported in the literature. Thus, it becomes necessary to explore other strategies that could be used to address the numerous challenges.



L1- L6- Lean Construction techniques
S1- S6- Safety issues
N1,N2- Negative impacts on safety
R- Strategies for addressing challenges
S- Strategies for addressing negative impacts
P1, P2- Positive impacts

Figure 3. 2 Conceptual Framework

3.9.5 Negative Impacts

Despite the safety benefits of Lean Construction techniques reported in the literature, a number of studies (Green 2002; Fucini and Fucini 1993) suggest that the application of Lean techniques in the construction sector may result in some negative impact on safety since they may create conditions that could lead to accidents. Though this experience has not been identified in the literature, its possible occurrence is considered in the framework. Furthermore, this will be investigated through contacts with Lean practicing organisations. Nevertheless, the occurrence of such negative impacts will have to be avoided or addressed in order to realise the targeted benefits.

3.9.6 Strategies for addressing the Negative Impacts

In a situation where any negative safety impact is noticed or identified from contact with Lean practitioners, this section of the framework presents ways or strategies that could be used to address them so that its benefits can be realised. Depending on the nature of the negative impacts, recommendations (R and S) can be drawn on how the negative impacts can be addressed to achieve a positive outcome.

3.9.7 Outcome

These are the results that companies engaged in Lean Construction practice want to achieve from its application. The key expected outcome is improvement in safety. However, improvement in safety can result in other indirect benefits. Some of the indirect outcomes or benefits of safety improvement are reduction of project overall cost and duration, employee satisfaction, more productivity, resources efficiency, better image of the organisation and industry as a whole, among others.

3.10 Summary

A review of the Lean Construction tools shows that besides reducing cost and project duration, they have some safety benefits. It was found that there are 3 major categories of studies on the relationships between Lean Construction techniques and safety practices on construction sites. The first category of studies argued that the application of Lean principles on construction sites could expose workers to poor safety conditions. However, apart from these studies not based on empirical evidence, they do not clarify how Lean Construction practice could impact negatively on safety.

Therefore, empirical evidence is required for this group's claim/ argument to stand/ be valid.

Conversely, the second group of studies claims that Lean Construction techniques could improve safety without stating how they do so. Finally, the third category of studies specifically identifies 11 ways by which Lean Construction techniques can impact on safety on construction sites. However, these ways or antecedents had received little or no empirical examination. In addition, the chapter further identified 12 potential relationships between the onsite causes and certain lean techniques based on a logical analysis. These relationships could also be prone to several challenges that are related to education, financial, technical and cultural issues. Thus, further investigation is required on how they could be addressed.

The 23 potential relationships between the identified individual Lean Construction techniques and their applicable safety issues were mapped out in the form of a Matrix and then conceptually linked to related issues to demonstrate how Lean Construction techniques could be utilised to promote safety. Therefore, this chapter has addressed the second research objective and partially addressed the third research objective. However, the framework developed was based on relationships identified from existing literature based on logical analysis and past studies that lack adequate empirical evidence. It therefore becomes necessary to collect data which will serve as empirical evidence to establish these relationships and explore other ways Lean Construction practice impacts on safety. In doing so, there was also a need to adopt the most appropriate methodology in conducting the exploratory study. The next chapter discusses the research methodology adopted in conducting the exploratory study and in validating the conceptual framework.

Chapter 4: Research Methodology

4.0 Introduction

Having reviewed the relevant literature for the research in the previous chapters, it is now imperative to demonstrate the philosophical principles behind the research and how it was designed to address its objectives. This chapter therefore discusses the methodology of inquiry for the research. It commences with the various approaches to knowledge claims and selection of the appropriate approach by which the research was pursued. The chapter also deliberates on the research strategy adopted, the research population and its sampling, ethical issues in research and how they were addressed. It then concludes with a discussion on the methods that were used to solicit requisite data as well as how the data was obtained and analysed to further develop and test the framework. The graphical representation of the processes for the execution of the research methodology is shown in Figure 4.1.

4.1 Research Approach

The literature identified three main approaches to knowledge claims, that is, the paradigms within which social science research is carried-out. These are quantitative, qualitative and mixed methods approaches (Creswell, 2009). Three predominant knowledge claims' principles determine an approach to knowledge claims; quantitative, qualitative or mixed methods approach. At the heart of these principles is ontology, which focusses on explaining what constitutes knowledge and its origins. The remainder is epistemology, which deals with scope of knowledge and explained in terms of the relationship between a researcher and an object under inquiry, and finally methodology, which is how to find knowledge (Bryman 2008). Based on these underlying principles of knowledge claims, the section examines the three approaches to knowledge claims and outlines the approach that fostered this research.

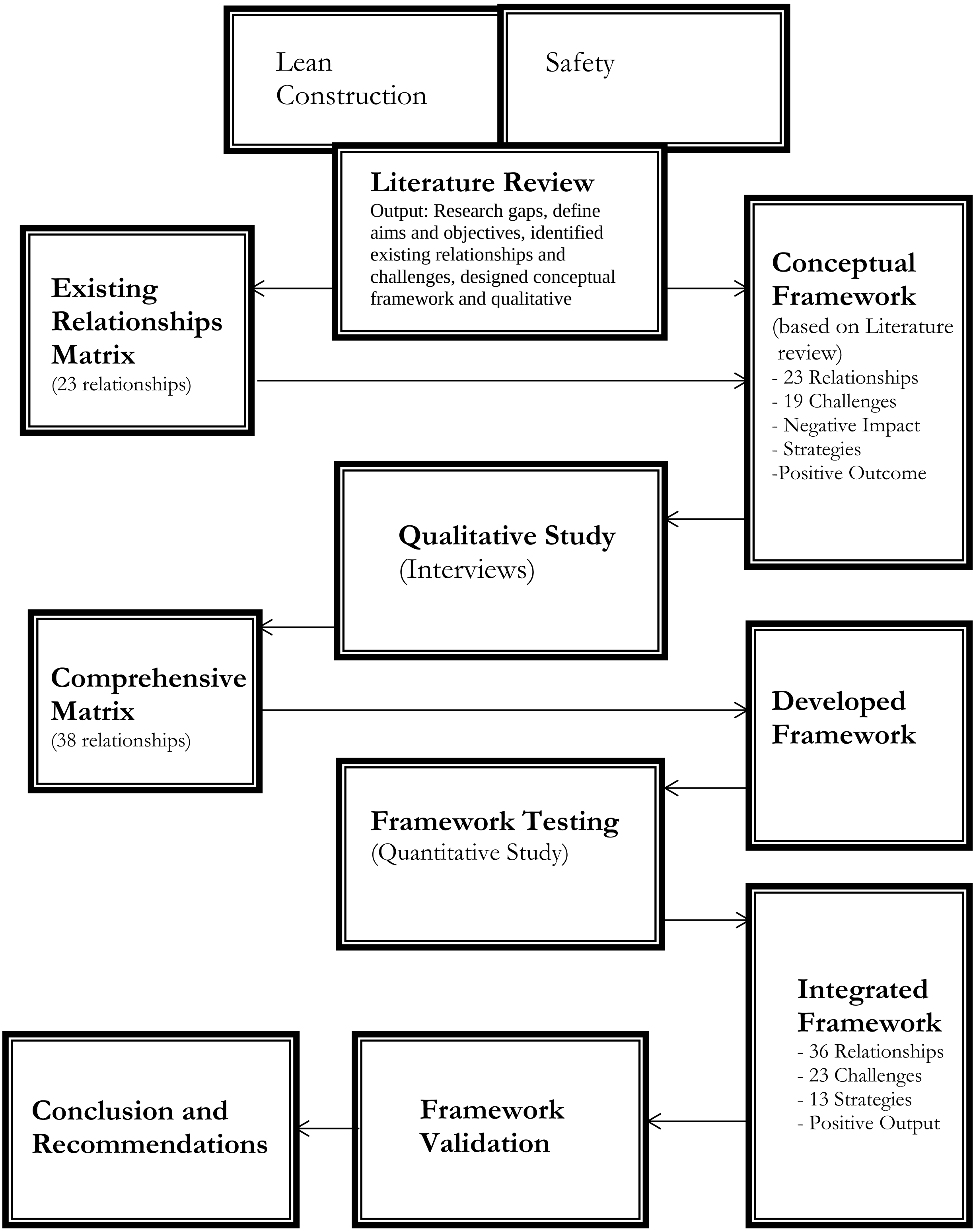


Figure 4. 1 Research Methodology

4.1.1 The Quantitative Research Approach

The quantitative research approach dominated research until perhaps the last four to five decades (Kerlinger and Lee 2000a). The approach also called “positivist” or “empiricist” is based on positivist claims to knowledge, which suggests that there is a single objective reality or truth in the world out there driven by undisputable natural laws, which is not based on human perception (Creswell 2009). This single objective reality is deterministic, which signifies a cause and effect relationship in social problem (Creswell 2003). Advocates of the quantitative research approach, therefore, apply rational methods that involve generation of numerical measurement of observation and verification of the theories and laws that govern the single objective reality out there in the world (Clarke and Dawson 1999). Epistemologically, however, quantitative research approach advocates adhere to objective stance in research, which suggests researchers must detach themselves from subject matter (object) of a research (Neuman 2006). This position is based on the need to avoid biases and subjectiveness in an inquiry (Creswell 2009).

From the foregoing discussion, the quantitative research approach in the context of social science is normally used to investigate a social or human problem based on testing theoretical assumptions upon collection and analysis of empirical data to determine whether the predictive generalisation of the theory is valid (Abdulai 2007; Creswell 2003, 2009). In summary, the quantitative research approach is characterised by the followings:

- The researcher is kept distant and independent from the sample to achieve an objective and unbiased assessment of the situation.
- It uses a deductive form of logical reasoning, such that concepts, variables and hypothesis are chosen and maintained from the beginning to the end of the study.
- It often uses statistical packages to carry out descriptive and inferential numerical analysis of the data, so as to test the reliability and validity of the results.

- The literature review provides the direction for the research. Based on it, a framework is developed and data is collected and analysed for the purpose of testing the validity or generalisation of the framework.

4.1.2 Qualitative Research Approach

Unlike the quantitative research approach, qualitative research approach emerged about five decades ago (Kerlinger and Lee 2000a). This approach is also referred to as social constructivism and interpretivism, among others (Creswell 2009). Despite its connection to several world views, the main philosophical assumption that drives this approach is the social constructionist philosophical assumption which is based on relative ontology (Guba 1990). This ontological stance prescribes that there is no single objective reality out there in the world contrary to the position of quantitative research advocates or positivists (Creswell 2009). Thus, from the viewpoint of qualitative research, there are multiple truths or realities out there in the world, as such, individuals and groups may construct their own truths or realities depending on their socio-economic, political and cultural background and/or experiences. Consequently, the qualitative researcher ought to record and report on all the various versions of the truths or realities, but not to identify which one of them is close to the truth (Hammond 2006).

Based on the ontological stance of social constructionists, qualitative research paradigm advocates for getting close to the subject matter under inquiry (Abdulai 2007; Bryman 2008; Neuman 2006). This stance is contrary to quantitative research paradigm position that rejects such practice to ensure that the research is devoid of biases and subjectiveness. However, advocates of qualitative research paradigm criticises this quantitative research approach position on the grounds that undertaking such research is not attainable. The real world situation is that quantitative researchers always return to the social world to ascertain and confer meaning to findings from their research (Guba and Lincoln 1989). Therefore, getting close to people or objects of a study to learn and understand their point of view is very vital. Furthermore, the basic difference between physical and social sciences is that methods used in the physical may not necessarily be suitable for the study of phenomena in the social science (Creswell 2009).

Qualitative research approach, thus, has inductive orientation and involves exploring to understand a social or human problem in which data is mostly collected from participants in their natural setting using emerging flexible questions and procedures (Creswell 2009). This research approach, however, has several designs such as grounded theory, phenomenology, ethnography, narrative and case study (Creswell 2009).

- In ethnography, an intact cultural group is studied in its natural settings over a long period of time (Flick 2006; Creswell 2009), with data collected through observation and interviews.

- In grounded theory design, processes, interactions, or actions grounded in the views of the participants are used to develop a general abstract theory (Creswell 2003), with data collected and refined in multiple stages. At each of the different stages, the researcher identifies similarities, differences and interrelationships of information to develop a grounded theory (Neuman 2006).

- In case studies, the researcher makes an in-depth study and analysis of an activity, process, event or people over time (Yin 2009).

- Phenomenological design involves studying a phenomena based on human experiences and their description of the phenomena (Gomm 2008) to develop meaningful patterns about that phenomenon. In narrative research, the researcher studies the life of one or more individuals. The researcher collects information from the individuals about their lives and rearranges the information in a more organised and systematic way that makes meaning using both the narrators' and researchers' views (Creswell 2003).

4.1.3 The Mixed Methods Approach

The mixed methods approach also known as multi-methodology is a relatively new research approach (Creswell 2009). This approach is based on the philosophical position of pragmatism, which advocates for combination of philosophies and methods for addressing social problems (Denscombe 2007). The rationale behind the pragmatic position is that truth is what works at a particular point in time, therefore, it is vital that researchers lay emphasis on the social problem in focus and assemble all the necessary philosophies, tools and methods for addressing the problem (Collins *et al.*, 2006). In essence, the approach is a combination of both quantitative and qualitative research approaches and comes in three different designs; sequential, concurrent and transformational (Creswell 2009).

4.2 Choice of Research Approach

Having discussed the various research approaches often used for social science inquiries it is now expedient to demonstrate how the research approach for the study was selected. To begin with, it is important to state that conventionally the choice of research approach is usually a challenge, due largely to the debate over years on the best research approach. However, it has been established that no one research approach is better than the other because all the approaches have their own merits and demerits (Bowling 2002). As such, it is recommended that the adoption of a particular research approach must be supported by clear basis for its adoption (Hammond 2006). To this extent, therefore, several reasons are usually articulated in the current literature for selection of research approaches. In the main, these include the research problem, the research audience, the availability of resources and the personal experience of the researcher (Abdulai 2007). These are discussed below.

4.2.1 The Research Problem:

The nature of the research problem determines the kind of method to be adopted in the research. For instance, if the problem is about testing a theory by establishing the magnitude of a causal relationship using identified variables then a quantitative method is considered as the best approach (Creswell 2009). On the other hand, if the problem involves trying to understand a phenomenon, exploring a concept or identifying the variables to examine, then a qualitative approach is the most appropriate. It can also be adopted where little or no research has been done on the concept. In a situation where both the quantitative and qualitative approach cannot be used alone to best address the research problem, the researcher can use a mixed method approach.

4.2.2 Personal Experience of the Researcher:

The researchers' experience or training in using data collection and analysis methods determine the type of approach to adopt. A quantitative method could be adopted where the researcher is good in using statistical tools, and computer statistical software like the SPSS (Naoum 2008). On the contrary, a qualitative method could be used where the researcher is good in conducting interviews, writing in a literary way and making observations (Creswell 2009). Some researchers could be familiar with both methods; hence, they could use the mixed method approach where it is necessary. However, the researcher should have adequate time and financial resources to adopt the mixed method approach because it consumes extra time to collect and analyse both quantitative and qualitative data.

4.2.3 Audience:

The findings of a research are normally disseminated to an audience. These could be organisations, journal editors, conference attendees and colleagues, among others. The experience of the audience with quantitative or qualitative method could influence the kind of approach to be adopted (Naoum 2013).

This study seeks to establish the nature of the relationship between Lean Construction techniques and safety in the construction industry with emphasis on contracting organisations in the UK. However, whilst the literature is, to some extent, prevalent with the relationships between Lean Construction techniques and safety issues in the UK construction industry, such relationships are set out based on little or no empirical evidences (Nahmens and Ikuma 2009). This suggests that the identified relationships may not be exhaustive enough or some do not actually exist, as such, there is need for exploration to fully ascertain the relationships. Given the foregoing, the mixed methods research approach is comparatively more suitable to addressing the research problem. Therefore, the approach was adopted for this study.

The mixed method approach adopted has the following merits (Denscombe 2010):

1. **Exploration and Generalisation**: While the qualitative approach was used to explore and wholistically identify the relationships, the quantitative method was used to confirm the relationships, test the framework and generalise (infer) the findings.
2. **Widening findings**: The quantitative method helped in widening the findings while the qualitative made them deeper.
3. **Improved confidence and accuracy**: The findings of the qualitative and literature review were further checked using the quantitative method to improve confidence in the accuracy of the findings.
4. **Validity**: the quantitative method was used to test the different components of the conceptual framework.
5. **A more complete picture**: Findings from the quantitative when added to the qualitative gave a more complete picture and full account of the relationship explored.
6. **Compensating the strengths and weaknesses of both methods**: For instance, qualitative approach gave an in-depth understanding but it did not cover a large sample, while the quantitative approach covered a large sample across wider geographical areas within a much shorter period. However, it did not provide information as deep as the qualitative approach.

4.2.4 Epistemological and Ontological Stance of the Research

Qualitative approach predominantly emphasizes on the generation of theories rather than testing and verification of the theories (Creswell 2009). Epistemologically, qualitative lays emphasis on the ways in which individuals interprete their social world, what is termed interpretivism, rather than the natural scientific model or positivism adopted in quantitative approach (Bryman 2013). Based on this, a qualitative approach was adopted to develop the framework at the first stage. Hence, the first stage of the research adopted constructionism as its ontological stance of the initial stage of the study while its epistemological stance is interpretivism.

The second stage of the research involves testing the framework. Hence, a quantitative approach was adopted. This indicates that the research adopted an objectivist approach as its ontological stance and a positivist approach as its epistemological stance at the second stage.

4.3 Research Strategy

The mixed methods approach has been selected for this research, however, in order to make the research operational a practical strategy needs to be designed to that effect. The main strategies previously identified under the mixed methods approach were sequential, concurrent and transformational. The sequential strategy or design operates by undertaking a research with a particular research approach and then subsequently follows it up with another approach (Creswell 2009). This, for example, may involve undertaking a research first with the qualitative approach and then later with the quantitative approach or vice-versa. Under concurrent design, both the quantitative and qualitative approaches are merged together to collect data at the same period to provide a platform for comprehensive analysis and examination of the research problem (Creswell 2003, 2009). The transformational strategy involves using a theoretical lens as an overarching perspective within a research design that collects both qualitative and quantitative data. The qualitative and quantitative data could be collected sequentially or concurrently. Due to the scarceness of written work on this strategy, there is little guidance on how it can be adopted (Croswell 2009).

In consonance with the research problem, the sequential design or strategy was adopted commencing initially with the qualitative approach and later the quantitative approach. Under this arrangement, three steps were followed. The first step involved examination of the relevant literature to identify the Lean Construction technique factors that impact on safety within the UK construction industry. The literature review initially devised a conceptual framework which attempts to explain how Lean Construction techniques could be used to promote safety on construction sites. It was established that it is necessary to empirically examine the soundness of the conceptual framework in respect to the relationships between Lean techniques and safety issues, the challenges that could be encountered n applying the techniques, the negative impacts that could arise, and the strategies that could be used in addressing both the challenges and the negative impacts. This approach of verifying the soundness and robustness of a conceptualised view of a phenomenon was also adopted by Ankrah

(2007), Tuuli (2009) and Manu (2012). Therefore the second step focused on interaction with experienced Lean Construction practitioners to authenticate the impact factors and safety issues that were identified in the present literature, identify additional areas of interactions between Lean Construction and safety, ascertain the relationship between both Lean techniques and safety issues and reflect the findings on the conceptual framework. The third and final step was devoted to testing the findings across the different components of the conceptual framework using a quantitative approach.

Following the initial literature examination, the phenomenology research design was adopted to address the second stage of the research. The phenomenology strategy focuses on people's experiences of phenomena and the interpretation derived from them (Gomm 2008). Generally, phenomenology can be conceived both as a philosophy and strategy (Creswell 2003). As a philosophical principle, it is one of the main underpinnings of the constructionists and interpretivists claims to knowledge (Bryman 2008). As a strategy, it entails studying a certain number of subjects through extensive engagements with them to develop patterns and relationships from the meaning attributed to the phenomenon (Creswell 2009). As such, data for relevant studies is collected based on research participants points of view, understanding and the meaning they attribute to the subject matter of the research (Bryman 2008; Denscombe 2007). This, thus, requires that researchers in typical phenomenology studies bracket their own perceptions and experiences so as to properly understand how research participants make sense of the world around them (Bryman 2008, Creswell 2009). Therefore, as noted earlier, phenomenology as applied to this research is used as a strategy and entailed engagements with experienced Lean Construction practitioners within the UK contracting organisations in pursuance of the second stage of the research.

Though there are several strategies under the quantitative research paradigm, the most well-known and fancied strategies are the experimental designs and survey research strategies (Creswell 2003, 2009). However, given the huge cost implications of experimental designs, their suitability for natural sciences and the fact that data was to be collected from research participants in their natural setting, the survey strategy was considered more suitable for the quantitative aspect of the research and was therefore adopted. Survey strategy entails collecting information from people in their natural setting by asking respondents questions (Denscombe 2007).

There are two main types of survey strategies; cross-sectional and longitudinal designs (De Vaus 2002). Longitudinal designs on one hand, come in three forms; trend, cohort and panel designs (Creswell 2009). Longitudinal designs, unlike cross-sectional design, mainly collect and analyse data on at least two different occasions (Oppenheim 1992; Bryman 2008). On the other hand, cross-sectional designs collect data at a particular point in time and analyses the data with respect to that time (Oppenheim 1992). Thus, the cross-sectional approach is more suitable for the research and was therefore adopted. The survey document was sent to all the organisations at the same period.

4.4 Data Collection Methods

This research employs both qualitative and quantitative methods of data collection. The different ways of collecting qualitative and quantitative data are discussed below.

4.4.1 Qualitative Data Collection Methods:

In a qualitative research, different forms of data can be collected in different ways; observation, interviews and documentary evidences (Abdulai 2007; De Vaus 2002). However, the most common method used to collect qualitative data for exploring a complex and subtle phenomena is an interview (Denscombe 2010), being a suitable way of collecting in-depth facts and opinions relating to the situation under study. The interviewer asks the respondents certain designed questions directly related to the research to collect answers vital to the research aims and objectives (Bailey 2007). An interview can be conducted in different ways. It can be administered through post, fax, telephone, web-based surveys or face-to-face. A face-to-face interview is adopted where an interpersonal contact is essential to describe the situation. In this case, the identity of the respondent is known. The face-to-face interview can be one-to-one or focus group interviews (De Vaus 2002).

The interview has many advantages. It provides an opportunity for close interaction between the interviewer and the respondent, allowing for high level of control of the interview process (Naoum 2008). There is also a higher chance of obtaining detailed and in depth information that is of high quality. Other advantages are in the accuracy of the answers, speed, high response rate, flexibility to reframe the questions and give the researcher chance to seek further clarification of the issues and obtain more details (Naoum 2013).

Interviews can be in an unstructured, structured or semi structured format (Bailey 2007). While the unstructured interview is similar to a conversation directly related to the research where the interviewee is allowed to develop ideas and follow their sequence of thought, in a structured interview, the different interviewees are presented with questions in the same order and virtually the same wording in a tightly controlled format of questions and answers (Silverman 2003). It is like a face-to-face administered questionnaire (Denscombe 2007). However, in semi-structured interviews, though the interviewer has a list of issues to be discussed, it is flexible in terms of the order in which the questions are answered and allows the respondent to develop ideas and speak widely on them. Therefore, a semi structured design was adopted.

4.4.2 Quantitative Data Collection Method

There are different ways of collecting data in quantitative research approach. These include observation, documentary evidence and questionnaires (Abdulai 2007). However, questionnaires are predominantly used in conducting surveys to find out facts, opinions and views of participants (Denscombe 2007). They mostly contain close-ended questions in which respondents are offered response choices like Yes or No, Agree or Disagree, ranking in order of preference or importance and so on (Denscombe 2010; Naoum 2007). These are easier to ask and respond to (Bryman 2008). In some cases, questionnaires contain open questions that seek to encourage the respondent to provide free responses without any choice (Neuman 2006; Denscombe 2007). In this case, spaces are provided for the respondents to express his/her opinion. However, the response may be too broad and difficult to analyse and interprete, unlike the close-ended questions.

Questionnaires may be administered in different ways; face-to-face interviews, postal, telephone, fax, internet or web-based surveys and so on (De Vaus 2002; Naoum 2008). These have various advantages and disadvantages. In the case of fax survey, the respondent and the researcher must have fax machines and the respondent may not be happy to use up his/her papers to print a questionnaire. This can affect his/her willingness to respond. A telephone or face-to-face interview may be expensive and time consuming to adopt especially when there is a large sample size. Furthermore, it can have some influence on the respondent. A web-based could be faster and cheaper however it demands the respondents' email addresses and internet facilities (Denscombe 2007). Similarly, a postal survey could have problems like poor response due to industrial fatigue, inaccurate response due to questions misinterpretation, lack of control over the respondent, and inability to make clarifications where necessary (Naoum 2013). To overcome these problems, the questionnaire had to be designed with simple and straightforward questions.

A postal questionnaire can be used to cover a large geographic area with less financial and human resources (Bryman 2008). The large geographical coverage could improve the validity of the results. Furthermore, a large number of responses could be realised within shorter period of time (Denscombe 2007). However, follow-ups may be necessary in some cases. Postal questionnaires give the respondent a chance to make further consultation before responding to some questions and the respondent can easily get back to the questionnaire and finish up the completion at convenient times. Thus, the postal approach was adopted.

4.5 Ethical Considerations

Ethical consideration is one of the most vital aspects of every field research (Bailey 2007). Ethical considerations are necessary to protect the participants and their organisations, gain their confidence and trust, promote the research quality, integrity, and guard against inappropriateness (Creswell 2009; Farell 2011). The researcher identified ethics as a priority in conducting this research from the topic selection, data collection and analysis to results dissemination. The entire research was conducted in a way that ensured that confidentiality and integrity of the participants were respected. Participants were fully informed about the aims and objectives of the research, and that their participation was on a voluntary basis and that at the end of the research, data collected from them will be destroyed (Oppenheim 1992; De Vaus 2002). They expressed consent to participate via email. In order to encourage full participation of the respondents, all the questions in the questionnaire were designed in such a way that they are free of threats, misguidance and deception (Neuman 2006; Bryman 2008). Prior to contacting the participants, an ethical approval was obtained from the University's School of Technology Ethics Committee in May 2011 (see Appendix B).

4.6 Sampling Techniques

A sample is a collection of respondents that are expected to fairly represent the population (Denscombe 2010). Depending on the population size, there are two major categories of sampling techniques; probability and non-probability sampling techniques (Naoum 2008). These are briefly discussed in the next section.

4.6.1 Probability Sample:

In a probability sample, all the members of the population are known even before a sample is drawn. Each member has a known chance of being selected as a sample (Bryman 2008). There are 4 types of probability sampling techniques:

4.6.1.1 Simple Random Sampling:

Here, each member has an equal opportunity of being included in the sample (Denscombe 2007). For instance, a researcher may put the names of all the members of a population in a hat, waddles the hat and thoughtlessly picks a portion of the names to form members of the sample. A major disadvantage is that the members may not be a true representative of the whole population (De Vaus 2002).

4.6.1.2 Stratified Random Sampling:

In this case, the population is first divided into certain categories based on different features (Bryman 2008). A relative number of the members is then drawn from each category (or stratum) to form the sample. This reduces the chances that the sample may not be a true representative of the population. For instance, if a class is stratified based on gender into 60 males and 40 females, 6 males and 4 females can be chosen to represent the class, as a sample.

4.6.1.3 Systematic Samples:

In this type of sampling, every nth member of the population is selected to form the sample (Denscombe 2007). A researcher first makes an ordered list of all the members of the population. The first member, starting point, is determined by a random selection. The size of the sample to be formed and the total number of the members will determine how many members of the population will be skipped. For example, if 10 samples are to be selected from a population of 100 members, every 9 or 10 members will be skipped i.e. every 10th member will be selected.

4.6.1.4 Cluster Sampling:

In this type of sampling, the researcher first develops a list of clusters or different groups that make up the population (De Vaus 2002). A sample of the clusters is then randomly selected. Data are then collected from each member of the randomly selected clusters. In other words, a random selection is made from the members of the clusters and data is then collected from these randomly selected members.

4.6.2 Non-probability Sampling

In this case, the researcher does not have a population where the total number of the members is known (Bryman 2008). Similarly, none of the members has a known, non-zero probability chance of being selected as a sample. Samples are selected based on their convenience and availability (Babbie 1990; Creswell 2009). In this case, extreme care is needed in generalising the findings from samples to the population. The different types of non-probability sampling techniques are:

4.6.2.1 Purposive Sampling

This is one of the most recommended sampling techniques for qualitative studies based on interviews (Bryman 2008). It is strategic technique where samples are selected based on their relevance to the research question (Denscombe 2010).

4.6.2.2 Convenience Sampling

In this form of sampling, the researcher does not have a special screening criterion. Data is collected from whoever is available or made available by an organisation and can participate in the study (Bryman 2008). It is necessary for the researcher to make full description of the participants studied when reporting the research findings.

4.6.2.3 Quota Sampling:

This is a technique where the researcher decides that different percentages of the sample should have certain different features (Denscombe 2007). In other words, the sample should be composed of certain number of objects of different features. Then the researcher simply continues to search for enough participants within each category until the set number or quantity is attained. For instance, a researcher may decide that his/her research require 30 primary school teachers, 30 secondary school teachers and 30 university lecturers.

4.6.2.4 Snowball Sampling

This is like two-stage purposive or convenience sampling. The researcher first collects samples that possess a certain criteria set for the study. However, in order to make up the size of participants required, the individuals then contact or introduce the researcher to other members that meet those particular criteria required of the participants (Oppenheim 1992; Denscombe 2007).

4.7 The Qualitative Study

4.7.1 Sampling Technique Adopted

The research is centred on developing a framework for utilising Lean Construction techniques to promote safety. Therefore, organisations applying lean are more familiar with the philosophy, principles and tools. Hence, the best samples in making this inquiry are construction organisations who have adopted lean on their project sites. However, because the total number of UK construction organisations implementing Lean Construction is unknown, a purposive non-probability sampling technique was adopted (Newman 2006; Bryman 2008). In this case, the researcher is dealing with a population where the total number of the members is not known. A list of organisations applying Lean Construction was collected from the UK body of Lean Construction institute (LCI-UK). The organisation overlooks Lean Construction practice in the UK and provides guide and support to organisations applying the concept. Another list of organisations applying Lean Construction was obtained from the Construction Lean Improvement Programme (CLIP) website. The CLIP was a programme created in 2003 and funded by the Building Research Establishment (BRE) to support UK organisations in applying Lean Construction based on recommendations of Sir John Egan's report "Rethinking Construction". However, it is important to note that some organisations may be applying lean and not registered with both CLIP and LCI-UK. In order to reach these organisations to make up a larger sample and increase participation, the snowball approach was also adopted (Bryman 2008; Denscombe 2010). In this case, at the end of each interview, the participants were requested to refer the interviewer to other organisations engaged in lean practice and willing to participate. At the end, a total of 54 lean practicing contracting organisations were invited to participate in the exploratory study (see Appendix D). However, only 10 organisations, each represented by one person, participated in the semi-structured interview held between July to November 2011. The response rate may be due to the fact that health and safety (H&S) is considered as a very sensitive issue in the UK construction industry and thus, a lot of organisations avoid participating in H&S research (Gibb *et al.*, 2002).

4.7.2 The Interview Design

The interviews were designed using standard best practice guidelines suggested by Bryman (2008). The semi-structured interview is in four sections (see Appendix E):

Section A requests information on the respondents and their organisation's profile. The interviewees were asked questions relating to their organisation, projects and area of operations, their individual working experience and their level of involvement in safety issues within their organisations.

Section B focuses on the current application of Lean Construction principles and tools in contracting organisations and examines their understanding of Lean Construction and purpose of engaging in Lean Construction practice.

Section C focuses on the impacts of Lean Construction practice on safety. To achieve an in-depth study level, they were also asked questions on how Lean Construction tools impact positively and/or negatively on their workers' safety.

Section D focuses on the benefits the organisations expect from applying Lean Construction, the challenges facing Lean Construction practice and how these could be addressed.

4.7.3 Data Analysis Method Adopted- Thematic Analysis

Ideas that emerged during the interviews were collected across the interviews, analysed and presented, in a way that is well understood, using a thematic analysis approach. As the name implies, the approach focusses on identifiable themes, which are "units derived from patterns such as conversation topics, vocabulary, recurring activities, feelings, etc" (Arson 1994).

Though thematic analysis is widely used in analysing qualitative data (Boyatzis 1998; Doulston 2001), it is rarely acknowledged (Braun and Clarke 2006). It is adopted without acknowledging its name unlike methods like grounded theory. This could be due to the fact that a number of studies do not consider it as an analytical method on its own. Boyatzis (1998) considers it as a stage within other qualitative data analytical methods such as grounded theory and phenomenological analysis. However, Braun and Clarke (2006) argued that it is a completely independent qualitative data analysis method in its own right. Nevertheless, it is sometimes labeled as "content analysis" or "discourse analysis", due to the similarity in their procedures (Braun and Wilkinson 2003).

Despite the wide adoption of thematic analysis, there is no agreed definition and standard procedures for conducting it (Attide-Stirling 2001; Boyatzis 1998; Tuckett 2005). Braune and Clarke (2006) defined it as a qualitative data analytical method that is used to identify, analyse and report the different themes within a data corpus. It is a strategy for categorising a qualitative data into dissolved patterns and developed themes. According to Boyatzis (1998), it is a process of encoding qualitative data. In other words, thematic analysis is a descriptive form of qualitative analysis where the researcher teases out and categorises issues from the data corpus into themes and patterns to show similitude of views across the participants.

The process of analysing qualitative data is seen as a complex and unclear process (Holloway and Toder 2003). However, thematic analysis tends to be a flexible approach that enables the researcher to bring out a rich and detailed meaning out of the data corpus (Braun and Clarke 2006). Therefore, the interviews were analysed based on Braun and Clarke (2006) and Creswell (2009) guide through the following stages:

1. **Familiarity with the data**

   At the first stage, the researcher familiarised himself with the data by entirely going through the data corpus, and searching for issues of interest and possible relationships between the issues without skipping any part of it. At this stage, the researcher started making notes and marking ideas for coding.

2. **Transcribing the data**

   Transcribing the data is a key phase of analysing a verbal qualitative data (Bird 2005), which is very vital in achieving an effective thematic analysis (Braun and Clarke 2006). The process made the researcher to become more familiar with the data. It was done rigorously and thoroughly to capture all verbal utterances in their true and original nature. Non-verbal utterances could not be captured being a telephone interview.

3. **Identification of meaningful issues and patterns**

   The transcripts were read over and over to identify patterns of meaning and issues of potential interest in the data, and how they relate with one another. The researcher identified phrases, words and segments that relate to the research question or problem and collected them together using codes.

4. **Generating the initial codes**

   Coding is a part of qualitative analysis procedures (Miles and Huberman 1994) where the segments are organised into meaningful categories (Tuckett 2005). They are the most basic element in the raw data that contributes in developing the best meaning out of the entire data. Codes were developed to serve as labels for words and phrases related to the theme and patterns in different sections of the transcripts. Codes were assigned to the extracts (phrases, words and segments) which are of interest to the research question.

5. **Collating the extracts**

The extracts were collated under the codes and the codes were grouped under the themes in a way that directly reflects the interview as a whole. Though this slightly required some interpretation from the researcher, the interpretations were kept at a minimum level. The researchers' personal views and thoughts were kept aside until the discussion stage.

The data extracts (words, phrases and segments) were collected under relevant themes and used to obtain a comprehensive discussion on the themes, ideas or issues that emerged from the interviewees' experience and opinions. The titles of the themes were derived from words or phrases contained in the transcripts.

6. **Reorganisation and renaming of themes**

   The different categories were studied and the segments were further redistributed under appropriate themes where such was required. This also involved re-examining the collated extracts under each theme with the original data to further confirm that it gives a correct picture of that theme (Anderson 2007). The themes were relabelled and renamed where appropriate. Some categories were also merged into one theme.

7. **Interpretation and Discussion**

   The findings across the various themes were interpreted, described and illustrated using the extracts and quotations from the original data. The findings were also discussed in relation to findings from the literature review and the conceptual framework to show contribution to knowledge and improve the framework.

4.7.4 Reliability and Validity Checks

The reliability and validity of a qualitative study are very vital in establishing confidence in the findings and conclusions. In order to achieve reliability, the transcripts were read over and over to ensure that they do not contain mistakes (Gibbs 2007). Furthermore, the coding was carefully cross-checked to ensure that the right codes are used to define every collection of words, phrases, and themes (Manu 2012). On the other hand, the validity was achieved by establishing the themes based on participants' perspectives and allowing the participants to comment on the findings (Creswell 2009).

4.8 The Quantitative Study

4.8.1 Sampling Technique

In line with the aims of the research, the study considered contracting organisations that are engaged in Lean Construction practice as the most suitable for drawing the sample for the quantitative study using purposive sampling technique (Newman 2006). However, the total number of UK contracting organisations implementing Lean Construction is unknown, as earlier mentioned, resulting in the researcher dealing with a population where the total number of the members is not known.

The 54 contracting organisations contacted during the qualitative study were used as samples for the quantitative study. As mentioned earlier, the list of these organisations was obtained through the LCI-UK and CLIP websites, snowballing and at Lean Construction seminars and workshops. Though the number of staff in each organisation is unknown, 10 questionnaires were sent to each organisation for fairness and equal representation in April 2012 (see Appendices G and H). This made up a total of 540 questionnaires. The 10 copies were addressed to the safety managers, construction managers, site managers and project managers of the organisations. These personnel were considered to be involved in the application of Lean Construction techniques on construction sites. To achieve a larger response, a reminder was sent to the companies in May 2012 to get more response (Neuman 2006; Ankrah 2007).

4.8.2 The Questionnaire Design

The design of a proper questionnaire plays a big role in achieving a very good response rate, which has been quite low, from the construction industry (Soetento 2006) and this could still be worse at the present economic recession.

The design of the questionnaire started with identifying a list of issues relating to the aims and objectives of the research. These issues were obtained from the literature review, the interviews conducted with Lean practicing companies and discussions held with Lean Construction academic experts. This proceeded with the development of an initial version of the questionnaire consisting of 5 sections (see Appendix H). To make the issues more explicit, based on findings from the piloting, the main questionnaire was refined into 6 sections as discussed below.

Section A requests information on the respondent and the organisation's profile. This involves the respondent's job title, his/her working experience, the organisation's years of Lean Construction practice, its number of employees, average value of projects and nature of projects. The data in this section is a nominal data.

Section B focuses on impacts of Lean Construction techniques on safety. This identifies which of the Lean Construction techniques have positive and/or negative impacts on workers' safety. The data in this section is an ordinal data.

Section C focuses on the potentiality of the Lean Construction techniques to reduce accident causations and exposure to risks on construction sites.

Section D examines and rates the factors that drive the various organisations to apply Lean Construction techniques on their construction sites.

Section E examines the challenges encountered by organisations applying Lean Construction techniques on construction sites.

Section F examines and rate the various output of applying Lean Construction techniques in the various organisations.

4.8.3 The Pilot Survey

The pilot survey was conducted in February 2012 to test the clarity of the questions, the comprehensiveness of the questionnaire, the feasibility of analysing the main questionnaire results to achieve a successful final survey (Oppenheim 1992; Denscombe 2007). A total of 50 questionnaires were sent out to practitioners, construction management researchers and academics with industrial working experience to invite them to participate in the piloting (see Appendix F). While 20 were addressed to researchers and academics, the remaining 30 were addressed to contracting organisations for the attention of the safety manager, project manager, site manager, site supervisor and site operatives. However, the respondents included quantity surveyors, architects, mechanical engineers, civil engineers, and project officers working on site as staff of the contracting organisations.

A total of 38 out of the 50 (76%) questionnaires sent out were returned and used for the piloting. The high response could be due to the fact that 38 questionnaires were handed out to the participants while 12 were sent out by email. While 22 (58%) of the respondents are still in practice, 16 (42%) of them are presently engaged in research and academic activities. Furthermore, 30 (79%) out of the 38 respondents have been involved in applying Lean techniques.

Besides completing the questionnaire, the participants were asked to give a feedback in terms of how long it takes them to fill it, the clarity of the questions and instructions, the layout and structure of the questionnaire and any other critical observation. A follow up interview with 2 construction management researchers, as suggested by Xiao (2002), yielded a more in-depth feedback on the clarity and feasibility of responding to the questionnaire. The major changes effected in the main questionnaire based on the piloting results are discussed below.

4.8.3.1 Completion time and length

It was initially estimated that the questionnaire will take 25 minutes. However, according to the respondents it was too long and rather took them an average of 40 minutes to complete. Hence, it was redesigned and reorganised. The questions seeking irrelevant and unnecessary information were reduced and completely removed in some cases (Denscombe 2007). Virtually repetitive questions were merged in a way that neither affects the research aims and objectives nor the research questions. The number of questions was reduced from about 160 to 109 questions and the questions were made more concise.

4.8.3.2 Clarity

In terms of clarity, the questions were made clearer in a way that the respondent can easily differentiate the information being sought (Denscombe 2007). The wordings of some questions were changed to avoid ambiguity (Oppenheim 1992; Bryman 2008).

4.8.3.3 Organisation

The Lean Construction techniques in Section C were classified into 7 categories to make the questionnaire more organised and easier to understand. The techniques that are related to handling the site operatives were classified as workers-related techniques. These include workers empowerment in assignment scheduling, correlating work methods with workers' ability, workers empowerment in assignment scheduling, workers involvement in work planning, and coordination of workers and simultaneous activities. The techniques that are related to planning activities on the site were classified as planning-related techniques. These include weekly work planning, collaborative planning and critical tasks planning. The techniques that are related to the site operations were classified as task related techniques. These include work methods' illustration, offsite manufacturing and pre-task hazard analysis. The techniques that are related to the site/ working environment were classified as workplace-related techniques. These include clean workplace and organisation of materials and plants. The techniques that are involved in exchanging information and ideas on site were classified as communication-related techniques. These are open communication between management and workers, and daily huddle meetings. The techniques that are related to improving visibility on site were classified as visual management techniques. These include safety signs and labels, visual safety borders and demarcation, visibility improvement. The remaining techniques were classified as "other Lean Construction techniques". These include visual inspection, standardisation, just-in-time, suppliers' involvement and process mapping.

4.8.3.4 Analysing the data

To give room for deeper analysis and optimise use of the results, sections E and F of the questionnaire were changed into scale types. Results obtained from the piloting were analysed using Statistical Package for the Social Sciences (SPSS) and STATA statistical software to confirm that the results are appropriate for the data analytic methods selected for the research. The data analysis methods applied were descriptive statistics, inferential statistics (chi-square and spearman correlation test), and inter-rater agreement test, which will be discussed below. However, STATA appeared less friendly in carrying out the inter-rater agreement test which is very vital in testing the validity of the relationships identified in the qualitative study. It tests the views as a group unlike the R software that test views on individual relationships/statements. The researcher underwent a training in the R software to effectively carry out the tests.

The respondents generally found the structure and layout of the questionnaire to be attractive. Hence, the corrected questionnaire was adopted as the main final questionnaire and the data was analysed using the SPSS and R statistical software. Besides the inter-rater agreement test, all other tests were done using SPSS.

4.8.4 Quantitative Data Analysis

The data was analysed using descriptive statistics, inferential statistics and inter-rater agreement test as discussed below. The process flowchart of the quantitative analysis processes is shown in Figure 4.2.

4.8.4.1 Descriptive Statistical data analysis

The purpose of descriptive statistics is to discover the patterns and processes of sample data. It is used to arrive at summary figures that describe the distribution of the sample data (Denscombe 2007). The nature of the variables administered in the questionnaire is univariate which means that the analysis method required is frequency distribution (De Vaus, 2002). Frequency distribution is a measure of how each scale level is distributed among the cases (respondents) and in addition to knowing how the data are distributed, it is extremely useful to be able to identify the typical scores, known as measures of central tendency (Kerr *et al*, 2002). The measures of central tendency are mean, median and mode (Neuman 2006; Naoum 2007). The mean is a measure of central tendency that indicates which response item has the highest tendency to represent the sample (Denscombe 2010). The median is the middle number in the range when arranged in an ascending or descending order, while the mode is the response item with the highest frequency of occurrence (Bryman 2008). The median and mode are not affected by the outliers/extreme values of the distribution (De Vaus 2002). However, they are not normally used for complex mathematical analysis. Therefore, the median and mode were used in carrying out further analysis. Nevertheless, the median is more ideal because it takes into account the fact that respondents' views can be ranked on ordinal variables (De Vaus 2002). Hence, they were adopted in the data analysis.

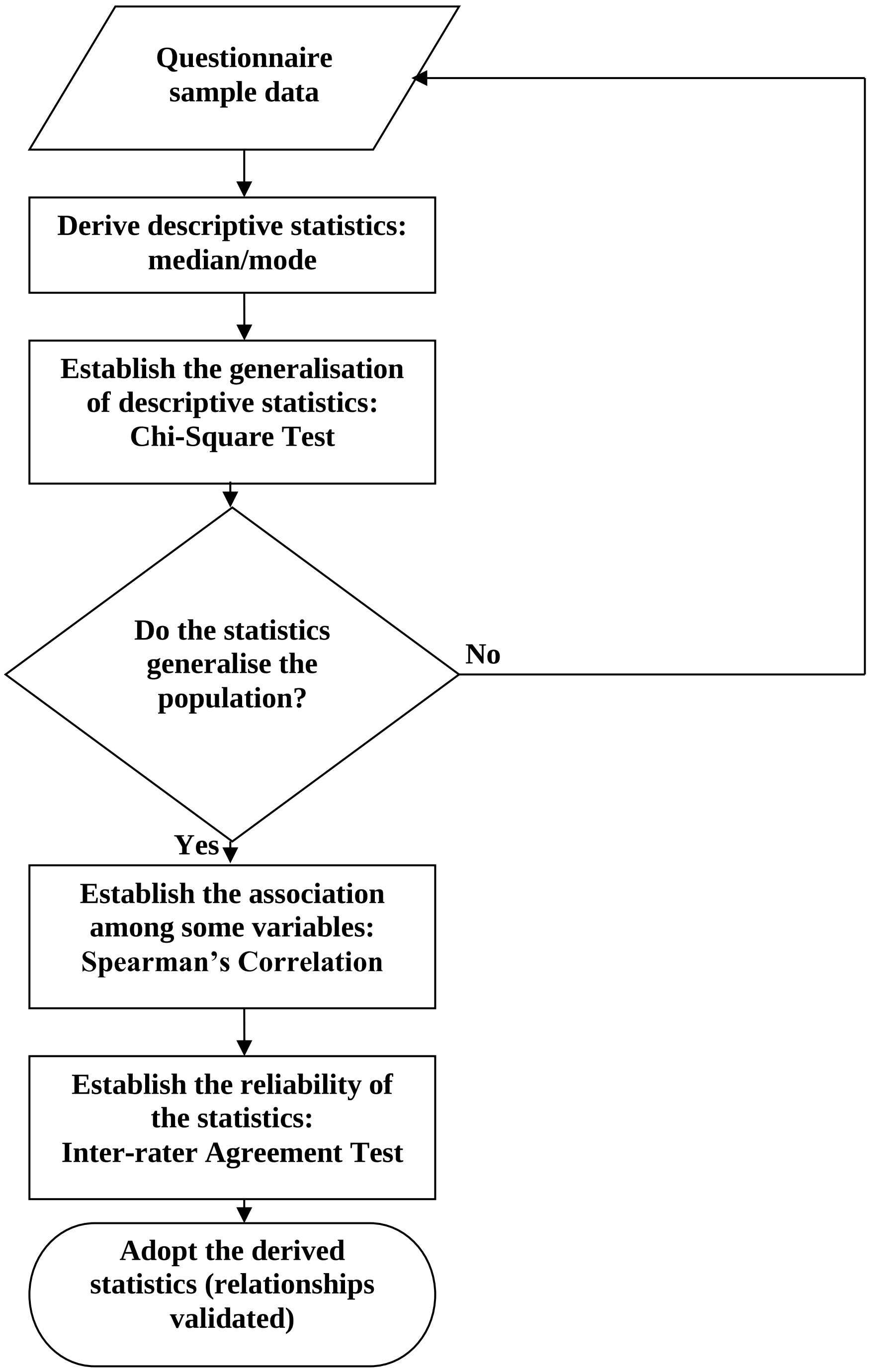


Figure 4. 2 Process Flowchart for Quantitative Data Analysis

A likert scale was used to collect the practitioners' views across sections B-F of the questionnaire. Likert scales fall within the ordinal level of measurement i.e. the response categories have a rank order but the intervals between values cannot be assumed to be equal (De Vaus 2002; Jamieson 2004; Denscombe 2007). For a scale to be at ordinal level of measurement, the categories comprising the scale are mutually exclusive and ordered. For instance, a scale that consist the following categories:

never, seldom, frequently and always are mutually exclusive and ordered in the sequence provided. Though the categories can be assigned the numerals 1, 2, 3, 4, the scale is ordinal (Knapp, 1990) and cannot be used for complex statistical analysis (De Vaus 2002; Bryman 2008) unlike interval and ratio data (Denscombe 2007). It is recommended that for ordinal data, median or mode should be employed as the measure of central tendency because the arithmetic manipulations required to calculate mean (and standard deviation) are inappropriate for ordinal data where the number generally represent verbal statements (Clegg 1998). Hence, they were used in carrying out the data analysis.

4.8.4.2 Ranking the Variables

The impacts of Lean Construction techniques on safety; drivers of Lean Construction practice in organisations; challenges to the implementation of Lean Construction techniques and the outcome of implementation of Lean Construction practice were ranked to demonstrate how the variables compare with one another. The ranking enables the organisations to allocate priorities in making decisions. The ranking indices (*R.I*) were derived according to the following formula (Fadiya *et al.*, 2012):

$$R.I_j = \sum_{i=1}^{5} w_i X_i ; w_i = i/5; X_i = n_i / N$$

where i represents rating categories; j represents the variables; n represents the number of respondents that chose category i and N represents the total number of respondents.

4.8.4.3 Inferential Statistics: Significance level testing

Significance level testing involves estimating how likely the sample pattern will hold in the population (Naoum 2013). The test start by assuming a particular pattern in the population and the assumption about the population is called a null hypothesis (De Vaus 2002). A significance level is typically set at 0.05, but sometimes it can be adjusted to as little as 0.01 or as much as 0.1. The decision to adjust it will be based on the tolerance for the two types of error i.e. rejecting the null hypothesis that is true or not rejecting the hypothesis that is false (Mirabella, 2006). Rejecting the null hypothesis when it is true is called Type I error while accepting the hypothesis that is false is called Type II error. Adopting 0.05 significance level means there is higher probability of rejecting a true hypothesis while adopting 0.01 significance level means lower probability of rejecting a true hypothesis but a higher probability of accepting a false hypothesis (Kerr *et al.*, 2002; De Vaus, 2002). It is difficult to assess the probability of committing either of these two types of error but 0.05 is a compromise that attempts to minimise the probability of committing either of the two types of error (Kerr *et al.*, 2002). The appropriate inferential statistical analysis for ordinal data are those employing non-parametric tests such as Chi-Square, Spearman’s correlation, or Mann-Whitney U-test because parametric tests require data of interval or ratio level (Jamieson, 2004).

4.8.4.3.1 Chi-Square test

There are two types of chi-square test: the goodness of fit test and independency test. The independency test is used to check if there is an association between two set of variables (bivariate) (Denscombe 2010) while the goodness of fit test is used in univariate data to justify that the sample is a representation of the population once the differences between the expected and observed frequencies are significant (De Vaus 2002). It is also called One sample chi-square test (De Vaus 2002). It checks if the responses/distribution across the categories are similar or different by comparing the set of observed and expected data. It is a test of distribution to check if the categories are not equally selected by the respondents (De Vaus 2002). It starts by assuming that the population views are equally distributed across the response categories in each variable. If the p value is less than 0.05, the null hypothesis can be rejected, that is, the results are statistically significant. Hence, the goodness of fit test is adopted in this study. In this case, a variable with three or more categories can be tested whether the differences between the percentages across the categories is due to sampling error or is likely to reflect real percentage differences in the population (De Vaus, 2002). The null hypothesis is described as follows:

H_0: The percentages of all categories of each variable are equal in the underlying population.

4.8.4.3.2 Spearman’s Rank Correlation test

Spearman’s rank correlation is a non-parametric test which does not require the assumption of normality in the population (De Coster and Claypool, 2004). The test compares medians rather than means and this makes it appropriate for the ordinal data gathered in this research (Jamieson, 2004). Spearman's rank correlation is used to test the strength of the association between two variables using ordinal data (Denscombe 2010). It was used to test the strength of the association between the drivers to adopting Lean Construction in the organisations and outcomes of the application according to the formula (Assaf and Al-Hejji, 2006):

$$r_s = 1 - \frac{6\sum d_i^2}{n(n^2 - 1)}$$

Where:

d_i is the difference in the ranks given to the two variables of each driver and outcome

n is the number of pairs of ranks

r_s is the Spearman's rank correlation coefficient.

The correlation coefficient, a measure of relationship between a pair of variable, varies between +1 and -1 where +1 means a perfect positive relationship between the pair (association) while -1 means a perfect negative relationship between the pair (dissociation). As required of every hypothesis test, the null hypothesis of this test is expressed as follows:

H_0: There is no association between the pair of variables.

4.8.4.4 Inter-rater Agreement Test

The level of agreement or disagreement of the respondents on the existence of the potential relationships between Lean Construction techniques and safety issues were determined using the median values. However, in order to have confidence in interpreting the results, it was considered crucial to check the level of consensus among the raters/respondents. This was done through an inter-rater agreement test using R statistical software.

The inter-rater agreement test is a technical test that is carried out to evaluate the extent to which two or more respondents/raters tend to make exactly the same judgement about the rated subjects (Tinsley and Weiss 1975; Mandrekar 2011). It measures the level to which they agree among themselves in rating the same set of things (Burke and Dunlap 2002). This serves as a strong validation tool for the identified relationships. It gives a measure of the consistency of agreement between the raters/judges (Mandrekar 2011). The application of this method in organisational research has dramatically increased during the last two decades (Le Breton and Senter 2008).

The statistical test was carried out with R software based on the James *et al.,* (1984) single item inter-rater agreement index (rwg). The results (indices) are very useful in determining the reliability of a rating system itself (Banerjee *et al.,* 1999). They represent the level of consensus or homogeneity in the respondents rating or judgements. It is conventionally agreed that rwg values ≥ 0.70 are acceptable to show adequate agreement among the respondents (Manu *et al*., 2011).

4.8.4.5 Statistical Significance of Inter-rater test results

A single-item inter-rater agreement (Rwg) index of 0.7 is conventionally considered as an evidence for adequate agreement among the raters (Manu *et al*., 2011). In every inter-rater agreement test, there is a group size (ie the number of respondents making the rating) and number of response items from which the respondents make a choice to express their rating. According to Cohen *et al*., (2001), the rwg values vary significantly as the group size and number of response items varies. The study suggests that while the conventionally acceptable rwg value of 0.7 is reasonable to some configurations of group size and number of response items, it may not be reasonable in some configurations. This implies that 0.7 may not be adequate enough to show agreement at certain values of group size and numbers of items.

In order to determine the minimum Rwg values required to show adequate agreement for the group size (number of respondents) and number of items in this study, a statistical test of significance was carried out. The test determines the Rwg indices at certain levels of confidence intervals based on a number of simulation runs and uniform null distribution (Manu *et al*., 2011). In this case, based on 10,000 simulation runs (Bliese 2009), the Rwg values were determined at 95% confidence level (Dunlap *et al*., 2003). At 95% confidence level, the minimum Rwg value required to show adequate agreement is 0.76. This implies that only statement/ relationships with Rwg ≥ 0.76 have evidence of adequate agreements at 95% confidence level.

4.9 Summary

This chapter has presented the methodology carried out for the realisation of the objectives of this research. The research strategies and sampling techniques have been presented and the adoption of every strategy and technique was adequately justified.

In order to explore the relationship between Lean Construction practice and safety, based on experiences and understandings of Lean Construction practitioners, the research in the main, adopted a qualitative approach. Furthermore, the quantitative approach was subsequently used to measure the extent to which Lean techniques impact on safety and to test the validity of findings across the different components of the conceptual framework. Hence the research adopted a pragmatic approach combining both qualitative and quantitative approaches.

This qualitative data was analysed using thematic content analysis approach while the quantitative data was analysed using descriptive and inferential statistics, and inter-rater agreement tests. Having discussed the methodology adopted the next chapter presents the qualitative study findings.

Chapter 5: The Relevance of Lean Construction Techniques in Promoting Safety: Findings from the Qualitative Study

5.0 Introduction

The third objective of the research is to achieve a fully developed conceptual framework for utilising Lean techniques to promote safety. Pursuant to addressing this objective, the chapter presents an analysis of the data obtained through the qualitative study conducted to ascertain the safety relevance of Lean Construction techniques and the issues associated with using Lean Construction practice to promote safety in the UK contracting organisations. The findings will then be used to further develop and refine the conceptual framework.

5.1 Data Analysis

The interviews were analysed using a thematic analysis approach (Boyatzis 1998). The method is a suitable and flexible way of collecting and communicating ideas and patterns or themes that emerge during an interview (Aronson 1994). Furthermore, Braun and Clarke (2006) suggest that it enables the researcher to get a rich and detailed meaning out of the interview.

The interviews were recorded and transcribed verbatim to organise and prepare the data for analysis. On the average the interview lasted for about 45 minutes. The transcribed copy was read numerous times in order to have a good understanding of the general ideas and identify the crucial ideas across the interviews related to the aims and objectives of the study (Creswell 2006; Flick 2009).

Codes were assigned to words, phrases and segments within the data which are relevant to the research question (Boyatzis 1998). These codes were then categorised into potential themes. The coded words and segments were studied, reorganised and collated under relevant themes (Braun and Clarke 2006). For instance, data extracts like "saving money", "cost benefit" and "reduce cost" were coded as "cost reduction" and categorised under the theme "drivers to Lean Construction practice". The categorised extracts were further analysed to make a detail description of the different themes and patterns or relationships among them.

The different themes that were identified from the interview are the Lean Construction tools, the drivers for applying lean tools in the organisations, the positive and negative impacts of lean practice, challenges facing Lean Construction practice, the negative and positive impacts of Lean Construction practice on safety and the outcome of lean practice on the organisations.

5.2 The Interviewees'/Organisations' Profile

The interviews were held with the lean experts in the selected organisations. These personnel include the Contracts manager (R1), Project manager (R2), Best Practice manager (R3), Project leader (R4), Associate director/Best improvement manager (R5), Lean improvement manager (R6), business improvement manager (R7), Lean technical manager (R8), Operations manager (R9) and Project manager (R10). These are deeply involved in the whole lean implementation journey of their respective organisations.

5.2.1 Organisation Operations Area

The size of the organisations varies. They were classified based on EU classification of construction organisations into 1 small, 2 medium and 7 large organisations in accordance with number of employees as shown in Table 6.1. The organisations' geographical area of operations also reflects their sizes. The large organisations focus and operate in wider areas, for example, R3 operates in Europe and Asia; R8 in the whole of England; and R10 and R2 at a global level, while the smaller organisations operate in smaller areas, for example R6 in Greater London. Similarly, R4, the medium size organisation, operates in Birmingham, London, Liverpool, Warwick and Manchester. However, the organisations are willing to follow their usual clients beyond these areas of focus.

5.2.2 Working Experience

The level of working experience differs across the interviewees. R1, R4, R5, R7 and R8 have over 30 years of working experience; R9 has 19 years; R3 has 18 years; R10 has 12 years; while R2 and R5 have 4 and 5 years respectively. This reflects their rank in their organisations. The most experienced among them (R5) happen to be part of the top management. However, they are the champions of lean implementation in all the organisations. Therefore, they were in a good position to discuss the impact of Lean Construction tools on behalf of their organisations.

Table 5. 1 Sample characteristic

	Role	**Work experience (years)**	**Number of employees in organisation**	**Size of organisation**	**Operation areas**
R1	Contracts manager	30	352	Large	North-west England
R2	Project manager	4	19415	Large	Global
R3	Best practice manager	18	375	Large	Europe, Asia
R4	Project leader	32	130	Medium	Birmingham
R5	Best improvement manager	33	602	Large	Greater Midlands
R6	Lean improvement manager	5	40	Small	Greater London
R7	Business improvement manager	33	650	Large	Birmingham, London, Warwick, Liverpool, Manchester
R8	Lean technical manager	31	4000	Large	England
R9	Operations manager	19	80	Medium	West and East of Midlands
R10	Project manager	12	19000	Large	Global

5.2.3 Understanding of Lean Construction and its Application in Improving Safety

In terms of their understanding of Lean Construction, R2, R5 and R10 understand Lean Construction as what they could do to add value to their products at the minimum cost and time while minimising non-value adding activities. R1, R4 and R9 understand Lean Construction as delivering valuable products to the client in an efficient way. R6 considers Lean Construction as a way of minimising resources consumption through a smooth workflow.

Whilst both R3 and R5 consider lean practice as a way of delivering what the client wants at the minimum cost, according to R5, it is about adding value to what they provide to the client while minimising non-value adding processes. R7 however sees it a way of improving productivity and quality of work and services using same resources whereas R8 regards it as planning the production processes in a way that is efficient and finishable.

Generally, the interviewees understand Lean Construction as a way of minimising cost and time and adding value to the products. Though they seem to have a good understanding of the concept, they do not consider it to be a major way of improving safety in their organisations, despite a significant number of them discovering that its practice makes a positive impact on safety.

5.2.4 Relevance of Interviewee to Safety in the organisation

In terms of their involvement in safety issues, R1 to R10, with the exception of R6, are all actively involved in promoting safety issues within the organisation. R6 is only minimally involved. According to R5, "... *I work very closely with Health and safety manager looking at the processes and procedures and check list and sort of sharing best practice. I am not directly responsible for health and safety, I am responsible for sort of quality system in the business which also includes health and safety procedures…".* Hence, they were able to identify the safety impacts of lean practice in their organisations. However, according to R6, *"I am not actually looking at safety issues …. I am not related to any safety but if I see any health and safety hazard I do act accordingly".*

Hence, he was unable to comment deeply on how Lean Construction tools impact on safety.

5.3 Lean Construction Tools applied in the Organisations

Several Lean Construction tools have been developed based on Lean Construction principles to improve productivity and minimise resources consumption. Different organisations have developed and adopted various tools depending on the drivers. The analysis has identified 21 Lean Constructions tools across the organisations interviewed as shown in Table 5.2. These compose of tools that have safety relevance and those that have no relevance to safety but are applied in the organisations for certain benefits. Though the literature review focused mainly on lean tools that have safety relevance, some of the tools have already been identified from the literature review. These include 5S (house-keeping), 5 whys (root cause analysis), visual management, elements of Last Planner System, collaborative planning, offsite fabrication, process mapping, and daily huddle meeting. The others identified from the interview are continuous improvement, standardisation, design management, integrating planning and procurement, knowledge sharing, Kanban, suppliers' involvement, short term planning, problem solving tracker, materials waste elimination, Lean sigma and stakeholder management.

The organisations apply a number of Lean tools to aid the application of the principles. Though R6 is a small organisation, it is able to apply up to 5 different Lean tools, while R4, a medium organisation applies only collaborative planning. All the large organisations seem to apply more than two tools. For instance, R7 applies weekly work plan, collaborative planning, root cause analysis (5 Whys), suppliers' involvement and 5S (house-keeping). Collaborative planning appears to be the most common among the organisations.

Table 5. 2 Lean tools applied

	Lean tools applied	**Frequency of Occurrence**	**Organisations**
1.	Collaborative planning	8	10, 9, 8, 7, 6, 5, 4, 3
2.	5Whys (root cause analysis)	5	7, 6, 5, 2
3.	Visual management	4	10, 8, 5, 1
4.	Last Planner System	4	9, 7, 6
5.	5S (house-keeping)	3	8, 7, 5
6.	Continuous improvement	3	5, 3, 2
7.	Standardisation	2	9, 5
8.	Design management	2	6, 2
9.	Just-in-time	2	9, 1
10.	processing mapping	2	8, 3
11.	Suppliers’ involvement	2	8, 7
12.	Daily huddle meeting	1	5
13.	Integrating planning and procurement	1	6
14.	Knowledge sharing	1	2
15.	Offsite fabrication	1	1
16.	Short term planning	1	3
17.	Problem solving tracker	1	1
18.	Kanban	1	1
19.	Lean sigma	1	8
20.	Stakeholder management	1	10
21.	Materials waste elimination	1	10

Root cause analysis and visual management appear to be among the most commonly applied lean concepts. However, the visual management concept is applied in different ways across the organisations. R5 apply it in the form of Pareto charts while R1 uses daily task objective charts to communicate some information to workers.

The different organisations consider the application of these tools as a suitable way of achieving their goals and attaining their targets on cost reduction, project duration, safety, productivity and profit margins. These are what drove the organisations into engaging in Lean Construction practice. Therefore, the drivers or purpose of engaging in Lean Construction practice influence their decision in selecting only the appropriate tools they consider suitable in achieving their goals. The next section identified the drivers across the 10 organisations.

5.4 The Drivers for applying Lean Construction in the Organisations

The factors that drive the organisations to apply lean vary across the various organisations. As shown in Table 5.3, the interviews identified 18 different drivers, namely, time reduction benefits, cost reduction benefits, improve efficiency, improve product and services quality, reduce defects, enhance site conditions, enhance safety and image, improve presentation, deliver value for your clients, become leading edge, increase revenues and profits (internally), clients' satisfaction, economics, process improvement, market competition, smooth project delivery, improve safety, and realise benefits identified by the Latham and Egan Government reports. According to R10, their organisation was motivated by the need to improve their processes and deliver value to their clients.

Table 5. 3 Drivers for Lean application

	Drivers	Frequency of Occurrence	Organisations
1.	Cost reduction benefits	5	1, 3, 4, 6, 7
2.	Improve efficiency	4	1, 5, 8, 9
3.	Time reduction benefits	4	1, 3, 4, 7
4.	Improve product and services quality	3	1, 7, 9
5.	Deliver value for your clients	3	2, 3, 10
6.	Process improvement	3	3, 4, 10
7.	Clients satisfaction	2	6, 7
8.	Safety	2	5, 7
9.	Increase revenues and profits	2	2, 6
10.	Become a leading edge in the construction industry	2	2,6
11.	Smooth project delivery	2	8, 9
12.	Enhance site conditions	1	1
13.	Enhance image	1	1
14.	Improve presentation of products	1	1
15.	Economics	1	3
16.	Market competition	1	6
17.	Latham and Egan government reports	1	5
18.	Better project management	1	8

However, cost, time and efficiency appeared to be the most common drivers in all the organisations. Some organisations see improving efficiency through Lean practice as a way of minimising cost and time. According to R6, *"… we had to do something that will reduce our cost and therefore efficiency is only where we can go ahead. So that is why we chose to go Lean Construction"*.

Table 5. 4 Drivers to Lean practice: comparison with Literature review findings

	Interview Findings	**Literature Review Findings**
1.	Improve efficiency	Efficiency
2.	Improve product and services quality	Quality
3.	Increase revenues and profits (internally)	Decline in profit margin
4.	Market competition	Increased competition
5.	Clients satisfaction	Low customer satisfaction
6.	Cost reduction benefits	Cost overrun
7.	Time reduction benefits	Time overrun
8.	Deliver value for your clients	Elimination of non-value adding activities
9.	Become Leading edge	
10.	Improve presentation	
11.	Enhance site conditions	
12.	Economics	
13.	Process improvement	
14.	Enhance image	
15.	Smooth project delivery	
16.	Safety	
17.	Latham and Egan government reports	
18.	Better project management	

Table 5.3 shows that the organisations seemed to apply Lean Construction for many factors beyond cost and time benefits. However, the benefits seem to differ across the organisations. For instance, the Latham and Egan reports influenced only R5, market competition drove only R6. Furthermore, only R5 and R7 organisations identified improving safety as a driver for applying lean in their organisation. Therefore, safety do not appear to be a popular driver for applying Lean Construction in most of the organisations.

The drivers seem to play a major role in the organisations' decision to apply the selected tools. However, it is important to note that the organisations limited the application of the tools to only those they considered appropriate in addressing their purpose of engaging in Lean Construction practice.

A large number of the drivers, including safety, found in the interview were not found in the literature as shown in Table 5.4. This indicates that there is some gap between practice and theory as to the reasons why organisations apply Lean Construction.

5.5 Safety Impacts of Lean Construction Tools

The views of the interviewees on the impacts of Lean Construction practice on safety have been collected and studied along three categories. The first category specifically attached some benefits to particular lean tools. The second category sees the benefits realised as a collective impact of the tools and Lean Construction practice as a whole. The third category focused more on cost and time benefits of Lean Construction thereby giving little attention to its safety impacts. For instance, according to R8, though applying the tools has over the years contributed to improvement in the organisation's safety records, the organisation has not recorded adequate statistical data to make a conclusion on the safety impact of the individual Lean Construction tools they apply. In this case, the interviewees were unable to specifically say this impact was caused by this or those tools. However, this can be further investigated in a future research.

According to the first category, the following tools have some specific safety impacts:

a. Standardisation enables risks to be thoroughly understood and mitigated.

b. Offsite manufacturing reduces high risk site activities, site movements, site hazards (like noise and dust) and helps in control against environmental and weather effects.

c. Just-in-time results in less site congestion.

d. 5S makes sites to be more organised, safer and less congested.

e. Collaborative planning leads to better understanding and interaction among tradesmen, and raises general knowledge and awareness on safety issues among contractors.

f. Daily and weekly meetings improve communication and safety awareness, reduce risks and improve risk management. According to R5, all areas of risks in the works to be carried out on that day are identified and addressed during the meetings.

g. Continuous improvement principle improves safety management plan and selection of subcontractors based on safety records and workers with CSCS cards.

h. Weekly work planning improves site management.

i. Collaborative planning improves interaction among project team, improved communication, and reduced risk and exposure to risk.

j. Visual tools facilitate communication on site.

According to the second category, the following are the safety impacts realised from two or more tools:

a. Collaborative planning, Continuous improvement and process mapping lead to better planning of works.

b. Collaborative planning and suppliers involvement enable early identification and management of several risks and safer work methods.

c. 5S and Visual management techniques reduce trip hazards and improve site tidiness. Fire exits could be kept clear and free of obstruction.

d. Production planning and control and Collaborative planning improve communication and create awareness on risks associated with the job and also help to reduce risks and constraints on site.

e. Workers' empowerment and involvement in task planning motivates the workers and put in them interest and pleasure in the job.

According to the third category, the following are the safety benefits of Lean Construction practice:

a. Lean Construction practice helps to avoid clash and conflict among trades, which seems to have made some positive impact on safety.

b. Lean Construction practice generally improves communication in the organisation.

c. Lean Construction practice results in doing things in less time and steps. This reduces exposure to risk according to an interviewee.

d. Lean Construction tools help in ensuring work methods are understood, achieving standard operation procedures and reduced clashes between trades.

5.6 Safety Outcomes of Lean Construction Practice

The application of lean tools has also resulted in 13 different outcomes related to safety in the organisations as shown in Table 5.5. R3 and R4 were unable to specifically attach some safety outcomes to particular tools due to the numerous tools they were applying. However, they identified some effects made collectively by the application of the lean tools. In other words, the tools have collectively resulted in some effects on safety. These resultant outcomes stated by the various interviewees include: better and improved risk management; reduced traffic movements; reduced site hazards such as contamination, noise and dust; better site control (less weather effect); better planning of works; site organisation; better understanding of interaction between trade packages probably raised general knowledge about safety between the contractors; and reduced clash of trades. None of these outcomes seems to be negative.

Table 5. 5 Safety Benefits of Lean practice

	Safety Outcomes	Frequency of Occurrence	Organisations
1.	Improved risk management	4	1, 3, 8, 10
2.	Improved communication	4	3, 6, 8, 9
3.	Better planning of works	4	3, 4, 7, 8
4.	Site organisation	3	1, 2, 7
5.	Reduced exposure to risk	3	1, 5, 10
6.	Reduced clash of trades	3	4, 5, 6
7.	Improved safety management plan	2	8, 9
8.	Improved job knowledge	2	4, 8
9.	Environmentally controlled site	1	1
10.	Reduced site hazards	1	1,
11.	Reduced incident occurrence	1	5
12.	Reduced traffic movements	1	1
13.	Workers motivation	1	5

The organisations generally believe that Lean Construction practice has a positive outcome on safety. According to R9, *"…considering accidents and other hazardous events as a waste of time, materials, men, resources and everything, I believe Lean Construction has a very positive impact on health and safety."* Similarly, R5 said that "*I believe lean has a positive impact on health and safety, and makes sure that no shortcuts are taken that workplace has a clear, standard operating procedure for doing things that everyone* *understands the method statements."* Furthermore, R10 suggest that Lean Construction has no negative impact on safety.

All the interviewees believe that Lean Construction tools have positive impact on safety. The only negative impact identified is leadership conflict due to resistance in cultural change. However, this is not directly related to safety. Similarly, R8 believes that misinterpreting or misunderstanding Lean Construction as doing things quicker and faster gives the wrong impression that Lean Construction could have a negative impact on safety.

5.7 Outcomes of Lean Construction Practice in the Organisations

The contracting organisations have over the years of their Lean Construction journey discovered both positive and negative outcomes related the application of the various Lean Construction principles and tools in their activities. The positive and negative outcomes, according to the interviewees' observations, are discussed below.

5.7.1 Positive Outcomes of Lean Construction Practice in the Organisations

The application of the various lean tools has so far yielded a number of positive outcomes in the organisations as shown in Table 5.6. The interview identified 21 positive outcomes. These include cost certainty; programme certainty; improved quality; less defects at handover; reduced costs; reduced site waste streams; improved communication; improved presentation; reduced programme times; improved relationships with subcontractors; client satisfaction; faster flow of information; reduced services time; engagement in value-adding activities; and management satisfaction. According to R7, *"we believe at somewhere between £200,000 and £300,000 a year to our bottom line in terms of profit and lots of that are delivered through the collaborative planning and the reduction of construction times and on-time project delivery."*

Other positive outcomes realised from Lean Construction practice are improved cost control; better project output/ products; preventing some accidents from happening; convenience in workplace; integration of activities, improved communications, more efficient, and improved safety practice. According to R6, *"...information is now flowing very smooth, everybody is aware of where to get the information from and how to process* *it, and after processing how to disseminate it to other operatives on site. This is another achievement on this lean implementation."*

Some organisations have also realised some indirect positive outcomes from applying Lean. By improving efficiency, it has also made some organisations more competitive. According to R3, *"The most important is now we are much more efficient than we are 2 years ago. So we can actually compete in terms of price without compromising on the quality.* Furthermore, according to R7, *"we realised benefits through increased profits, empowered staff, more efficient processes and probably a different change compared to other contractors that are not applying lean".*

Table 5. 6 Positive Outcomes of Lean Construction practice

	Positive Outcomes	**Frequency of Occurrence**	**Organisations**
1.	Improved communications	7	1, 3, 4, 6, 7, 8, 9
2.	Safer practice	5	1, 3, 5, 7, 10
3.	Reduced programme times	5	2, 4, 5, 7, 8
4.	Reduced costs	5	1, 4, 5, 6, 7
5.	More efficient	4	1, 5, 6, 7
13.	Client satisfaction	4	3, 5, 6, 7
6.	Reduced site waste streams	3	5, 7, 9
7.	Improved relationships with Subcontractors	3	3, 4, 10
8.	Engagement in value- adding activities	2	2, 7
9.	Programme certainty	2	1, 3
10.	Cost certainty	2	1, 5
11.	Improved quality	2	1, 6
12.	Improved presentation	1	1
14.	Integration of activities	1	6
15.	Management satisfaction	1	7
16.	Faster flow of information	1	5
17.	Less defects at handover	1	1
18.	Improved cost control	1	7
19.	Better project output/ products	1	5
20.	Reduced accidents	1	5
21.	Convenience in workplace	1	1

5.7.2 Negative Outcomes of Lean Construction Practice in the Organisations

According to the respondents, Lean Construction practice has also resulted in some negative outcomes. These include culture clash; high training cost; misunderstandings among staff; lack of guarantee for returns; and the need for whole process buy-in before full benefits could be realised (i.e. need complete change/full implementation rather than haphazard implementation to realise full benefits).

R9 observed that due to the high demand and expectation on productivity, after applying Lean Construction in their organisation, there was pressure on workers to change their working culture. The pressure itself could have a negative impact on the workers because the resistance to the pressure and change in working culture could result to conflicts in the organisation. For instance, R8 identified slight conflict in their organisation due to resistance to these changes from workers. Similarly, according to R7, *"the negative impacts all come around change and change management and the fact that the industry is resistant to change".* This shows that the concept has both positive and negative outcomes on organisations. This will be further investigated in the quantitative study.

5.8 The Challenges encountered in Lean Construction practice

Though the application of lean has yielded a lot of benefits across the organisations, a lot of challenges are facing its implementation. A total of twelve challenges were identified across the organisations. According to some of the interviewees, the challenges facing Lean Construction practice in these organisations include resistance to cultural change, complexity, lack of cooperation, non-compliance with instructions, lack of long term forecast and investment, lack of Lean knowledge, Old school thinkers not seeing the long term goal, and old school mentality. According to R5, "y*ou get the impression that well if it is not burst, why try to fix it."*

Others are cost of implementation, long implementation time, lack of long term forecast and investment, change in attitude and thinking, low effort to learn, misconceptions about Lean, lack of management support, high expectations from the management, and changing people's behaviour. According to R4, *"changing people's behaviour is the most challenging thing."*

Table 5. 7 Challenges facing Lean practice in the organisations

	Challenges	**Frequency of Occurrence**	**Organisations**
1.	Changing employees' working culture	8	10, 9, 7, 6, 5, 3, 2, 1
2.	Cost of implementation	4	9, 7, 4, 2
3.	Lack of Lean knowledge	3	10, 9, 1
4.	Long implementation time	2	7, 2
5.	Complexity	2	8, 1
6.	Lack of cooperation from employees	2	5, 6
7.	Lack of incentives	1	4
8.	Lack of long term forecast and investment	1	3
9.	Low effort to learn	1	9
10.	Misconceptions about Lean	1	8
11.	High expectations from management	1	3

There seems to be more challenges identified in the literature review than in the interview. This is due to more cases studied in the review within and beyond the UK. The challenges faced by different organisations differ, hence, the more organisations studied the more challenges identified. These are also restricted to contracting organisations not all construction organisations. These challenges are discussed in more details below based on views across the participants or practitioners.

5.8.1 Changing Employees' Working Culture

According to R10, R9, R7, R6, R5, R3, R2 and R1, one of the major problems facing organisations is employees' resistance to change in their working culture. A lot of workers find it difficult to change the way they learned to do things and the ways they do things. Some workers say *"if it is not broken, why fix it?"* Despite learning the benefits attached to doing things differently to improve productivity, some workers prefer to do things the traditional way. This is seen as a big challenge to Lean Construction practice in most of the organisations.

5.8.2 Lack of Long Term Forecast and Investment

R3 sees lack of long term forecast of the benefits of Lean Construction to the organisation, among the top management members, as a challenge to Lean Construction practice in their organisation. Though the organisation is engaged in Lean practice, the poor or negative long term forecast of its potentiality could contribute to inadequate support and commitment from the management to full investment in implementing Lean Construction. However, this problem seems to be peculiar to the management of this organisation (R3).

5.8.3 Long Implementation Time

According to R2, Lean Construction is a continuous improvement endless journey that may take a long period to be fully implemented. For instance, time is needed to train the workers, apply the principles, select the appropriate tools to use and implement them on site, manage change to working culture, and carry out an evaluation to see areas of improvement. Therefore, this is seen as a long term investment by R7 and R2.

5.8.4 Cost of Implementation

R9, R7, R 4 and R2 are of the opinion that one of the challenges of Lean Construction practice is the cost attached to its implementation. This involves the cost of training the workers, consultancy fees, conducting workshops, purchasing signs and labels to be used in visual management, alerts and so on. Some of the production hours may also be consumed in daily huddle meetings. The four organisations see these expenses as high and costly.

5.8.5 Misconceptions about Lean Construction

R8 noted that one of the challenges facing Lean Construction practice is the wrong conception a lot of workers have about the philosophy. Some workers see it as a way of saving production cost by reducing the number of staff, paying fewer wages to them or forcing them to complete a task within a shorter period so that they will be paid for less number of hours. Some staff also misinterpret it as doing the job quicker. This makes some workers to dislike the approach and as such they tend to give inadequate cooperation to achieve its full implementation. Though only R8 identified this problem, it seems to be a common problem among Lean practicing organisations.

5.8.6 High Expectations from Management

As R3 observed, another challenge facing Lean Construction practice is management high expectations as soon as Lean Construction is implemented. The management of some organisations expect to see sudden, significant and dramatic achievements in terms of productivity, cost, time and other factors that drive them to apply Lean Construction. This tends to result is putting pressure on the workers and in some cases slight disappointments when the outcome is below expectation.

5.8.7 Lack of Lean knowledge

According to R9, the fact that Lean Construction was adopted from Lean manufacturing, a lot of the workers and even their managers are not familiar with the Lean concepts. Lean Construction cannot be practiced without knowledge of the Lean concepts. R1 and R10 suggested that this tends to discourage some organisations in its implementation. They see it as an entirely new project management approach that they have to learn from basics.

Another challenge according to R9 is that the workers are not very keen on learning the Lean Construction principles and tools introduced by the organisation. In some cases, they are a bit reluctant in acquiring Lean Construction knowledge.

5.8.8 Complexity

Lean Construction does not just involve applying Lean Construction tools on site. It also involves developing a culture among the staff for a continuous and endless pursuit of improvement across all units of the organisation. In addition to the site environment, Lean is practiced even in administrative activities within the office environment. R1 and R8 observed that this is seen as a too intricate and complex practice to adopt among some workers.

5.8.9 Lack of Cooperation from Employees

In order to achieve the objectives of an organisation, its employees must work together harmoniously as a team and comply with instructions issued to them. R5 noted that some workers do not give the necessary cooperation required to site managers and Lean improvement managers.

It is quite a difficult task for an employee to change his or her working culture especially when there is no incentive for doing so. R6 further noted that some workers do not comply with the instructions given to them by the Lean implementation consultants or the site manager when applying the Lean Construction tools on site. However, this problem does not seem to be common in other organisations.

5.8.10 Lack of Incentives

An incentive is a reward given to a worker for improvement in productivity, which could be in the form of money, events or items. Though workers are paid to do their job, it will be good to appreciate their efforts with additional rewards especially when they do all that they are required to do. Sometimes incentives incite a worker to put greater efforts in carrying out a task. Lean Construction demands that they work smartly and efficiently to increase the productivity. According to R4, one of the challenges affecting Lean Construction practice in some organisations is that the workers are not given any reward besides their normal wages for being more smart and efficient. Despite improvement in the productivity due to Lean Construction practice, no incentives are given to the workers. However, only R4 identified this problem.

Nature of Challenges

Table 5.9 shows that 4 out of the 11 challenges are related to human issues (36%), 1 is financial (9%), 2 are technical (18%), 1 is educational (9%), 3 are related to the management (28%) and none is related to the government. This shows that most of the challenges facing Lean Construction practice are related to the human nature of the worker. This is then followed by challenges related to the management of the organisations.

The role of the management is critical in addressing the challenges facing Lean Construction practice. This could also be seen from the strategies identified by the respondents. A large number of the strategies are issues that could solely be implemented by the management. However, the workers also have a role to play in implementing the strategies.

Table 5. 8 Nature of Challenges facing Lean practice in the organisations

Challenges	**Nature of Challenge**
Resistance to culture change	Human related
Lack of cooperation from employees	Human related
Lack of long term forecast and investment	Management related
Long implementation time	Technical issue
Cost of implementation	Financial issue
Lack of Lean knowledge	Educational issue
Lack of incentives	Management related
Misconceptions about lean	Human related
Complexity of lean implementation	Technical issue
High expectations from management	Management related

Table 5. 9 Challenges to Lean practice in comparison with literature review findings

	Interview Findings	**Literature Review Findings**
1.	Changing employees' working culture	Cultural change
2.	Lack of long term forecast and investment	Lack of team spirit
3.	Long implementation time	Absence of long term planning
4.	Cost of implementation	Long implementation period
5.	Low effort to learn	Implementation cost
6.	Misconceptions about Lean	Leadership conflict
7.	High expectations from management	Over enthusiasms
8.	Non-compliance with instructions	Fear of unfamiliar practices
9.	Lack of Lean knowledge	Lack of wholistic implementation
10.	Complexity	Difficulty in understanding concepts
11.	Lack of cooperation	Lack of agreed implementation methodology
12.	Lack of incentives	Lack of technical skills
13.		High-level illiteracy
14.		Inadequate knowledge
15.		Inadequate projects' funding
16.		Inflation
17.		Lack of self-criticism
18.		Poor performance measurement strategies
19.		Inadequate resources

5.9 Strategies that could be used to Overcome the Challenges

In order to achieve a smooth application of lean tools and realise its full benefits, the challenges identified have to be addressed. The various interviewees have identified different strategies that could be used in overcoming the various challenges as shown in Table 5.11. These include simplifying the language of Lean, total belief by site team and supply chain, education, getting clients to insist on lean application, legislative requirements, and publication of results. When organisations see the results published and wide range of benefits realised, it may be easier for them to get on board. Other strategies identified from the interview that could be used to address the barriers are site team must buy in, call it business improvement instead of Lean, reduce the fear/reservations among workers, top management involvement and support, persistence, robust planning, enlighten people on need for change, enlightenment on its benefits/business improvement, reduce high expectation on outcome, gradual step-by-step implementation, and workers involvement and empowerment.

Table 5. 10 Strategies to overcome the Challenges

	Strategies	**Frequency of Occurrence**	**Organisations**
1.	Enlightenment on benefits of lean and need for change	5	10, 8, 7, 5, 1
2.	Publication of results	5	10, 8, 7, 5, 4
3.	Reduce the fear/ reservations	4	8, 5, 4, 3
4.	Education	3	10, 9, 2
5.	Get clients to insist on lean application	2	8, 2
6.	Workers involvement and empowerment	2	5
7.	Top management involvement and support	2	5, 3
8.	Persistence	2	7, 6
9.	Total belief by site team and supply chain	2	4, 2
10.	Government policies and legislation	2	10, 2
11.	Simplify the language of Lean	1	1
12.	Robust planning	1	6
13.	Gradual step-by-step implementation	1	9

5.9.1 Enlightenment on Benefits of Lean Construction Practice and the need for Change

According to R5, R8 and R10, organisations should engage their staff in enlightenment meetings, workshops and other events on the benefits of Lean Construction practice.

Furthermore, R1 and R7 suggested that the workers should be enlightened on the need for change from the traditional practice to Lean practice and should also be made to understand the benefits for the change in order to give full cooperation to the management.

The staff should be made to understand the difference between Lean and non-Lean practices and what Lean project management is all about. They should be well informed about how they can comply with the demands of lean practices and in what way they are expected to make continuous improvements. This strategy could help in addressing challenges like difficulties in changing working culture, misconceptions about lean and lack of cooperation from employees.

5.9.2 Simplify the Language of Lean Construction

The terminologies adopted in manufacturing should as much as possible be minimised. In order to achieve a more successful and smooth implementation of Lean Construction, R1 suggested that the organisation should use terms that are simple to understand. All the instructions, directive and terms should be made easy to understand in order to achieve compliance and successful execution of the assigned task(s). This strategy could help in addressing challenges like lack of Lean knowledge and complexity of lean practice.

5.9.3 Total belief by Site Team and Supply Chain

The organisation should ensure that the site team and the supply chain have confidence in the new approach. According to R2, they should be made to have trust in it, mentally accept it and have full conviction that it is a progressive change.

According to R4, the site team as well as staff involved in the implementation of Lean Construction in the organisation should agree with the idea and accept it as a system that is worth pursuing. Hence, they must buy-in the ideas. This strategy could help in addressing challenges like difficulties in changing working culture and lack of cooperation from employees.

5.9.4 Education

According to R10, R 9 and R2, the organisation should engage its staff in a learning process to acquire all the necessary knowledge and skills required to achieve a smooth and full implementation of Lean Construction principles and tools in the organisation. These could involve organising a workshop for the staff, a training session with Lean consultants or funding them to attend a Lean Construction seminar. However, a tailored programme that satisfies the company's needs is more suitable and preferable.

Staff training is a key to the success of Lean Construction practice. Training prepares both managers and employees to effectively utilise developments brought by growth in technology (Corner 2001). The workforce must be adequately trained to fully and successfully accomplish tasks using the new tools and approach. This strategy could help in addressing challenges like difficulties in changing working culture, misconceptions about lean, lack of Lean knowledge, complexity of lean practice and lack of cooperation from employees.

5.9.5 Get Clients to insist on Lean Application

R8 and R2 suggested that the construction industry should get clients to firmly demand for Lean Construction approach to managing their projects. They may insist that this is inserted in the contract terms. Just like the demands on sustainability, the clients should be persistent on applying Lean principles to execute the project.

5.9.6 Publication of Results

According to R10, R8, R7, R5 and R4, the results of studies and benefits of Lean Construction practice should be communicated to the staff and even the public as a whole using printed materials like newspapers, building magazines, journals and so on. The organisation could also use TV programmes and other audio-visual aids to communicate the results and benefits. This strategy could help in addressing challenges like difficulties in changing working culture and high expectations from management.

5.9.7 Reduce the Fear/ Reservations

The organisation should ensure that the fear built in the staff due to misconceptions and misunderstanding of Lean Construction practice is cleared from their minds. They should not see it as a threat to their job or welfare. According to R8 and R3, this is necessary to clear away any reservations they have in their minds.

Due to the misconceptions and misunderstandings about Lean Construction among workers and some clients, to reduce the fear and reservations, R4 and R5 prefer to call it "business improvement" in their organisations rather than Lean Construction. In this case, the workers and clients see the organisation's Lean approach as an innovative continuous business improvement strategy rather than an entirely new method of doing business. This strategy could help in addressing challenges like difficulties in changing working culture and lack of cooperation from employees.

5.9.8 Top Management Involvement and Support

According to R3 and R5, the top management must be fully involved in the implementation of the concepts. They must engage themselves in continuous improvement activities and provide all the necessary facilities and incentives required to support and strengthen the staff. This strategy could help in addressing challenges like lack of long term forecast and investment, long implementation time, high expectations from management, lack of incentives and lack of cooperation from employees.

5.9.9 Persistence

In order to achieve a sustainable Lean Construction practice, R6 and R7 suggested that the entire staff must put continued effort. Despite the obstacles and inconveniences of changing working culture, they should be firm and steadfast towards satisfying the demands of becoming a Lean organisation.

5.9.10 Robust Planning

According to R6, the organisations must develop a very rich and strong programme to achieve a smooth implementation. A vigorous scheme should be formulated to aid the practice so that the goals can be obtained. This may involve making a policy in the organisation to achieve the objectives of Lean Construction practice. Robust planning could help in reducing the long implementation time, cost of implementing Lean Construction and complexity of lean practice.

5.9.11 Workers Involvement and Empowerment

R5 suggested that Lean practicing organisations should involve its staff, both senior and junior, in making decisions that relate to Lean Construction practice in the organisation. The staff should be given permission to say their views and should be authorised and empowered to make suggestions. This strategy could help in addressing challenges like difficulties in changing working culture and lack of cooperation from employees.

5.9.12 Government Policies and Legislations

According to R10, to further support Lean Construction practice, the UK government could introduce a policy that will encourage construction companies to engage in continuous improvement practices, like Lean Construction, to reduce construction waste and minimise waste of resources in construction projects.

The introduction of laws by the legislature, which is an arm of the government, is seen by R2 as another way of facilitating the full application of Lean among construction organisations.

5.9.13 Gradual Implementation of Lean Concepts

R9 suggested that a good way of overcoming the resistance to cultural change exhibited by workers in Lean practice is to avoid sudden one-off implementation of Lean principles and tools. The principles should be gradually taught and implemented in stages over a period of time. Similarly, when the organisations identify the tools that are relevant in achieving their targets, they should apply the tools in stages or one after the other, rather than many tools at a time. This strategy could help in addressing challenges like difficulties in changing working culture and complexity of Lean implementation.

Table 5. 11 Strategies for addressing the challenges in comparison with literature review findings

	Interview Findings	**Literature Review Findings**
1.	Enlightenment on benefits of lean and need for change	Awareness programs
2.	Publication of results	Staff training
3.	Reduce the fear/ reservations	Government policies
4.	Education	Education
5.	Get clients to insist on lean application	
6.	Workers involvement and empowerment	
7.	Top management involvement and support	
8.	Persistence	
9.	Total belief by site team and supply chain	
10.	Government policies and legislation	
11.	Simplify the language of Lean	
12.	Robust planning	
13.	Gradual step-by-step implementation	

Table 5.12 compares the strategies for addressing the challenges with those identified in the literature. Section 5.9.4 considers staff training as part of Lean education. Therefore, the

interview findings confirm all the strategies identified in the literature. These 13 strategies will be incorporated into the framework to guide the organisations in overcoming the challenges.

5.10 Implications of Findings on the Conceptual Framework

The aim of the interviews is to further explore the relationship between Lean Construction practice and safety so as to wwholistically identify how the application of Lean techniques could be used to promote safety, the challenges associated with Lean practice and the strategies that could be used to address them. Findings from the interview were then be used to refine and further develop the conceptual framework across different sections as discussed below. The developed framework is presented in Figure 5.1.

5.10.1 Input

The application of Lean principles is a basic requirement for every organisation adopting Lean Construction. The study shows that only the Lean tools and techniques that are relevant in achieving the aim of adopting Lean in an organisation are adopted. Therefore, since the purpose of adopting this framework is to promote safety in the organisation, the Lean techniques in the framework are limited to those labeled L1 to L21 as shown in the matrix in Table 5.12.

5.10.2 Processes (Relationships)

The literature review has identified a number of ways that showed how Lean Construction practice could impact on safety in two different categories. While the first category contains relationships established by previous studies based on little or no empirical evidence, the second category contains relationships established from logical conclusions based on critical review and analysis of literature relating to causes of accidents on the UK construction sites, accident causation models and the features of Lean Construction tools. Both categories were established (based on anecdotal evidences) without contact with Lean contracting organisations. From the exploratory studies conducted above, the following extracted relationships further show clearly how Lean Construction practice relates to safety:

a. Standardisation enables risks to be thoroughly understood and mitigated.

b. Offsite manufacturing reduces high risk site activities, site movements, site hazards.

c. Just-in-time results in less site congestion.

d. Collaborative planning lead to better planning of works, enables early identification and management of risks and selection of safer work methods, and raises general knowledge on safety issues and site awareness.

e. Process mapping leads to better planning of works.

f. Suppliers involvement enables early identification and management of risks and selection of safer work methods.

g. 5S improves site tidiness and reduces site congestion.

h. Visual management techniques reduce trip hazards.

i. Visualisation tools facilitate communication on site.

j. Daily and weekly meetings improve communication and safety awareness, reduce risks and improve risk management.

k. Production planning and control help to reduce risks on site.

l. Workers' empowerment and involvement in task planning motivate the workers.

m. Weekly work planning improves site management.

These findings could be incorporated in the matrix shown in table 3.4 to make it more comprehensive as shown in table 5.13 below.

Table 5. 12 Possible Interaction Matrix of Lean Construction Techniques and Safety issues

	Workers' empowerment in assignment scheduling	Correlating work methods with workers' skills	Correlating tasks with workers' ability	Pre-task hazard analysis	Weekly work planning	Coordinating workers and simultaneous activities	Daily huddle meetings	Critical tasks planning	Work methods' illustration	Safety signs and labels	Visual safety borders and demarcations	Visibility improvement	Visual inspection	Clean workplace	Material and plants' organisation	Workers involvement in task planning	Process Mapping	Collaborative planning	Just-in-time	Standardisation	Offsite fabrication	Integrated supplychain
Safety issues/ Onsite accident causations	L1	L2	L3	L 4	L 5	L6	L 7	L 8	L9	L 10	L11	L12	L 13	L14	L15	L16	L17	L18	L19	L20	L21	L22
S1. Tripping												B										
S2. Excessive stress	R[1]	R																				
S3. Poor supervision													R[1]									
S4. Poor planning					R[1]			R									I	I				
S5. Falling objects															R[1]							
S6. Organisational pressure	R																					
S7. Poor communication							B			B												
S8. Site hazards (eg dust, noise)														R							I	
S9. Human/ Judgement error										R	R	R[1]										
S10. Risk identificatn & reduction				R			B											I		I		I
S11. Lack of knowledge									R[1]													
S12. Lack of safety awareness							B											I				
S13. Physical and mental inability			R[1]																			
S14. Site congestion						R[1]								I	R[1]				I			
S15. Untidy site										I				B								
S16. Procedural issues									R[1]													
S17. High risk activities																					I	
S18. Lack of motivation																I						
S19. Poor work methods																		I				I
S20. Poor site management					I																	

The table shows the different Lean techniques that could be used to address certain safety issues in order to improve safety on construction site. These interactions are based on findings from the literature review and the qualitative study. Across the table are the Lean Construction techniques labeled L1-L22 while down the table are the safety issues labeled S1-S20. Based on findings from the literature review and the qualitative study, the letters R, R^1, I and B are used to indicate which of the Lean techniques could be used to address a particular cause of accident or a safety issue.

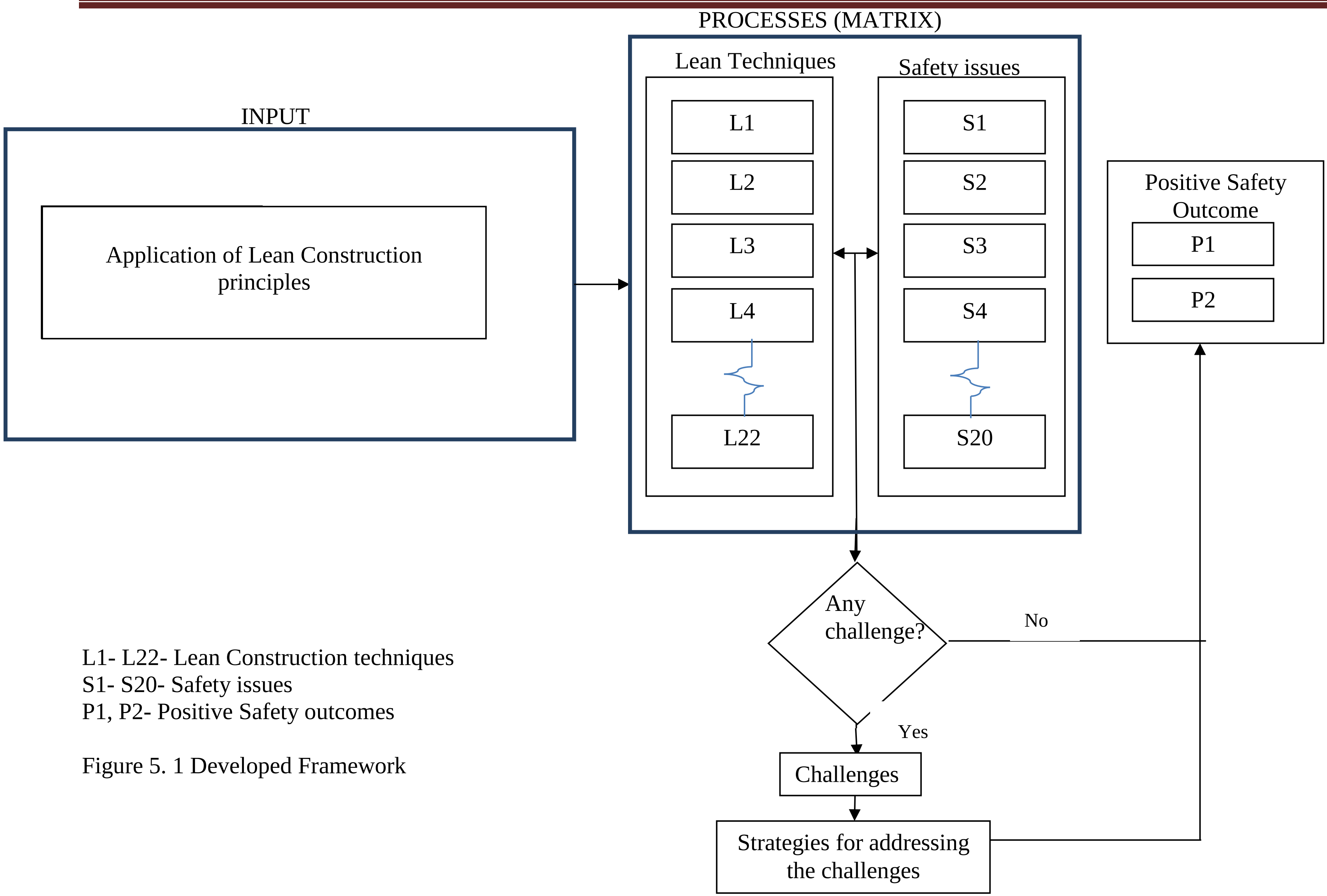
The 7 interactions labeled R are identified from past studies lacking empirical evidence only, the 10 interactions labeled R^1 are based on literature review findings only, the 15 interactions labeled I are based on findings from the qualitative study only, while the 6 interactions labeled B are based on findings from both the literature review and qualitative study. The matrix shows a total of 38 areas of possible interaction between Lean Construction practice and safety.

5.10.3 Challenges and Strategies for addressing them

The study also identified 10 additional challenges facing Lean Construction practice in contracting organisations. Similarly, it identified 13 strategies that could be used to address the challenges in order to realise the desired improvement in safety. Adding these findings to the conceptual framework makes it more comprehensive and robust.

5.10.4 Negative Impact on Safety

None of the participants witness a negative impact on safety resulting from Lean Construction practice. They all believed that Lean Construction tools rather have positive impact on safety. Therefore, no negative impact on safety was identified. Hence, this component was removed from the framework. However, this finding will be further verified in the quantitative study.



L1- L22- Lean Construction techniques
S1- S20- Safety issues
P1, P2- Positive Safety outcomes

Figure 5. 1 Developed Framework

5.11 Summary

The interview has explored the relevance of Lean Construction techniques in promoting safety across 10 Lean practicing contracting organisations of different sizes and engaged in different kind of projects across different locations within and outside the UK. As the interview findings have shown, the main purpose of applying lean in these organisations is to improve efficiency so that waste of resources can be minimised. Though improving safety is not the major driver for applying Lean Construction in the organisations, the participants were able to identify some of the impacts Lean Construction practice has made on safety on their construction sites. While some organisations related 21 impacts to specific Lean tools and techniques, some organisations related the impacts to general Lean Construction practice. However, all the impacts on safety reported are positive, none of the organisations reported any negative impact on safety. Furthermore, the participants reported that they have not witnessed any negative impact on safety relating to Lean Construction practice in their organisations. The negative impact is rather related to conflicts due to non-compliance with instructions. Therefore, no negative impact on safety was identified.

The drivers or purpose of engaging in Lean Construction practice have some influence on the kind of tools applied in the organisations. They select and apply only the kind of tools that would enable them to realise the targeted benefits of adopting Lean Construction principles in the organisation. Consequently, the difference or dissimilarity in drivers or purpose of applying Lean Construction seem to result in adopting different set of tools across the different organisations. Hence, organisations with similar drivers tend to adopt some tools in common. Furthermore, due to training cost, purpose of lean practice, organisational targets and implementation cost, some organisations apply fewer number of tools compared to others.

The exploratory study identified quite a large number of lean tools applied across these organisations. For example, collaborative planning is the most common tool applied across the UK organisations, while the Last Planner System seems to be the most commonly discussed tool among researchers and academicians. Though the tools applied vary across the organisations, in some cases, some organisations apply the same tool but in a different way.

For instance, some apply visual management in the form of Pareto charts while some use signs which are both part of the concept.

The chapter found that Lean Construction practice is faced with 10 different challenges in these organisations. Though 5 of them have already been identified in the literature, 5 appear to be new. The 5 new challenges are high expectations from the management, low efforts to learn, lack of long term forecast and investment, non-compliance with instructions, and lack of incentives. The industry’s resistance to change in behaviour/practice happened to be the most predominant challenge facing Lean Construction practice. Nevertheless, the participants have made numerous suggestions on how these challenges could be addressed in order to optimise the benefits of lean application. These include publication of results, training, knowledge sharing and enlightenment.

In order to fully address the third research objective, findings from the qualitative study were used to further develop and refine the conceptual framework in terms of its components and how the components interrelate to achieve improvement in safety. For instance, the findings also show that the organisations are not experiencing any negative impact related safety. Hence, the negative impact of Lean techniques on safety was removed from the framework.

Despite the wide literature reviewed, the 15 additional relationships identified from the interview could not be identified prior to the exploratory study and engagement with lean practitioners. In order to test the validity of all the 38 relationships and other components of the conceptual framework, using a large sample of Lean practicing contracting organisations, a quantitative study was adopted. The next chapter reports findings from the quantitative study.

CHAPTER 6: Assessment of the Conceptual Framework: Findings from the Quantitative Study

6.0 Introduction

The fourth objective of this research is to examine and test the different components of the conceptual framework to confirm the relationships and concepts presented in the framework. To address this objective, survey questionnaires were used to collect data from the Lean practicing contracting organisations on their views about the safety impact of Lean Construction tools. The questionnaire design and the research questions addressed have been discussed in chapter four. This chapter presents the responses to the survey, analyses of the survey data and discussion of the research findings. In the process of carrying out the analyses, the conceptual framework was tested across its individual components.

6.1 Data Analysis

The data was analysed using descriptive statistics, inferential statistics and inter-rater agreement test. The descriptive statistical analysis carried out include frequency distribution and measures of central tendency like median and mode while the inferential statistics include chi-square test and spearman correlation test. The inter-rater agreement test results were also tested for statistical significance.

6.2 Survey Response

Out of the 540 questionnaires posted to the Lean Construction practicing organisations, a total of 96 were returned (17% response rate), out of which only 92 were properly completed. The other 4 were not completed because some of the respondents have no knowledge on the impact of Lean techniques on safety while the others have very little experience and involvement in Lean Construction practice. The low response rate may be related to the poor survey response attitude of the UK construction industry (Xiao 2002) and to the lengthiness of the questionnaire (Ankrah 2007) which has 109 questions. Though the response rate may appear to be low, Soetento *et al.*, (2001) suggest that a response rate of 14.6% is the acceptable norm for comprehensive questionnaires. Similarly, the research conducted by Sutrisna (2002) had a lower response rate of 8.82%, when compared to this study.

6.3 Characteristics of the Respondents

Questions 1 and 2 of Section A of the questionnaire (see Appendix F) was analysed to classify the characteristics of the respondents. According to Figure 6.1, 45% of the respondents are health and safety managers, 12% are site managers, 13% are project managers, 4% are site supervisors while the remaining 26% was comprised of services engineers, civil engineers, structural engineers, quantity surveyors, and architects working within the contracting organisations. This indicates that health and safety managers were deeply involved in the survey and their views reasonably obtained.

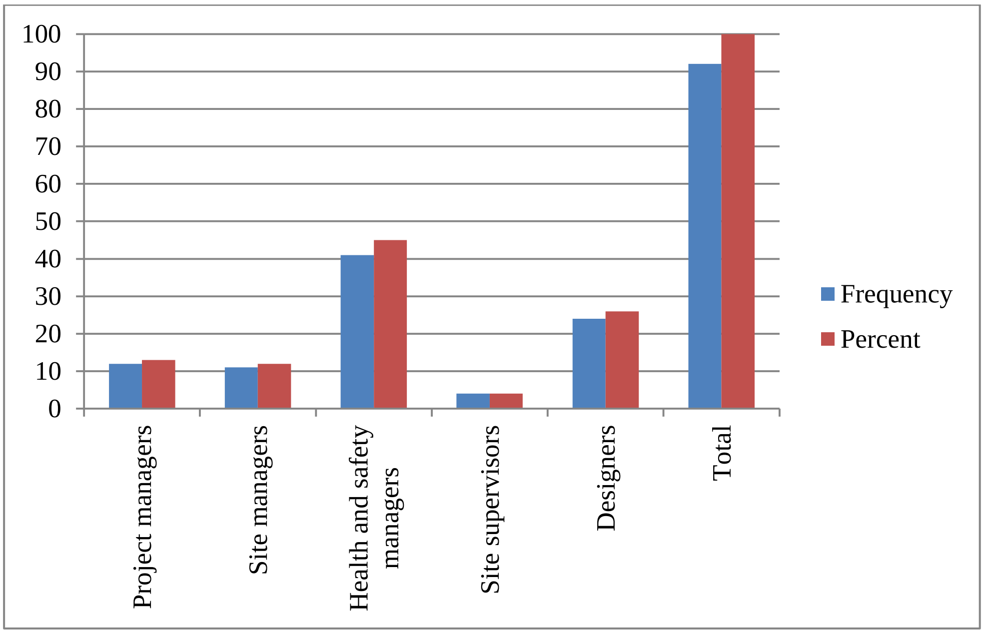


Figure 6. 1 Position in company

According to Figure 6.2, 66% of the respondents have a working experience of over 15 years, 15% have 11-15 years of working experience, 13% have been working in the construction industry for 6-10 years and only 1% of the respondents have 1-2 years of work experience. This indicates that over 80% of the respondents involved in the survey have more than 10 years of working experience and are very familiar with the site environment and causes of accident on site.

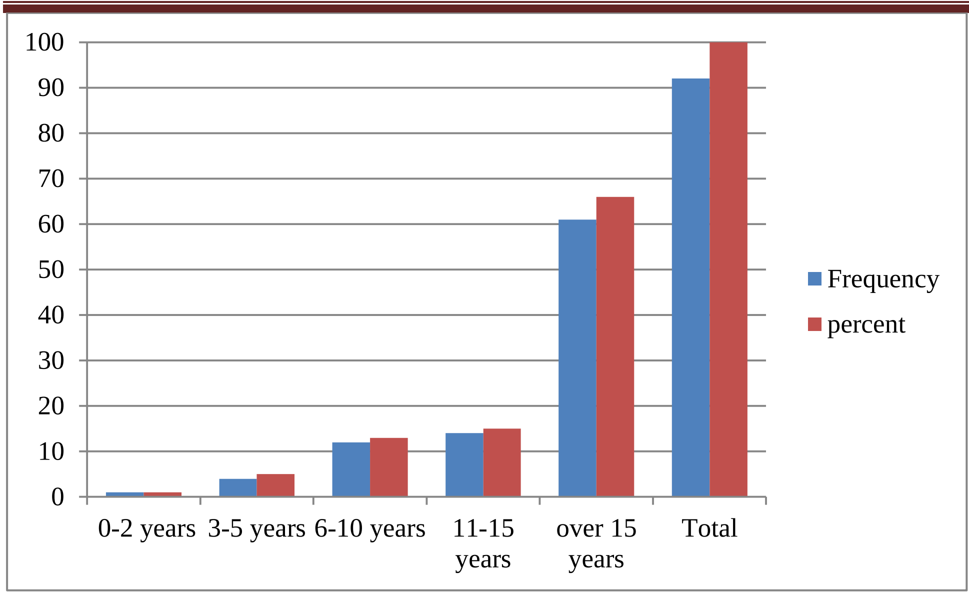


Figure 6. 2 Years of working experience

6.4 Characteristics of the Organisations

Question 3 was asked in order to ascertain the sizes (annual turnover and headcount) of the organisations on whose behalf the respondents responded to the questionnaire (see Appendix F). As shown in Figure 6.3, 52% of the organisations have over 250 employees, 29% have 51-250 employees, 15% have 11-50 while 3% and 1% have 6-10 and 1-5 employees respectively. This indicates that the questionnaires were mostly answered by large companies having more than 250 workers.

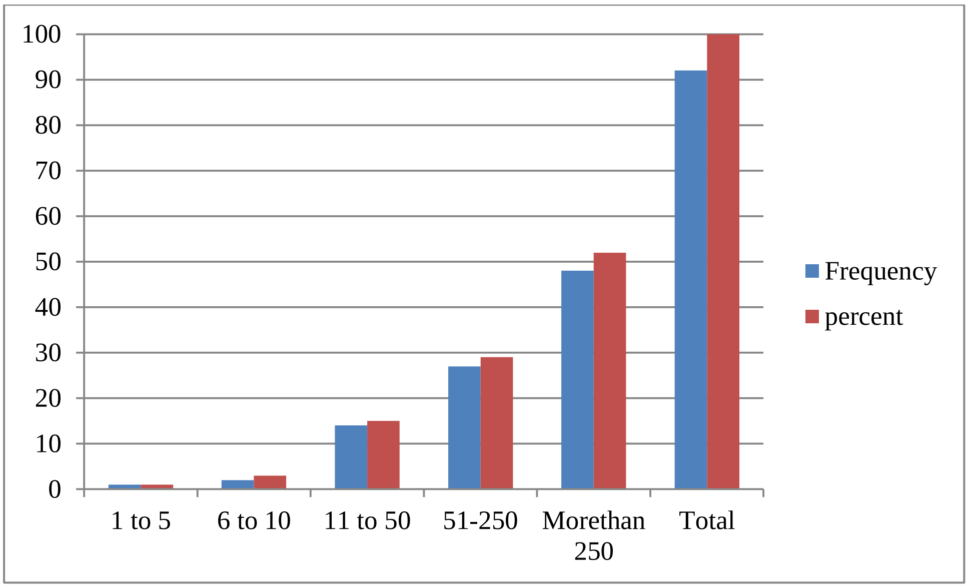


Figure 6. 3 Number of employees

With regard to average turnover of funds by the organisations (Figure 7.4), up to 43% of the companies that participated in the survey have an annual turnover of over £5 million, 22% have a turnover of £2.1 to 5 million, and only 7% have less than £1 million. This indicates that most of the questionnaires were mostly answered by companies involved in large projects.

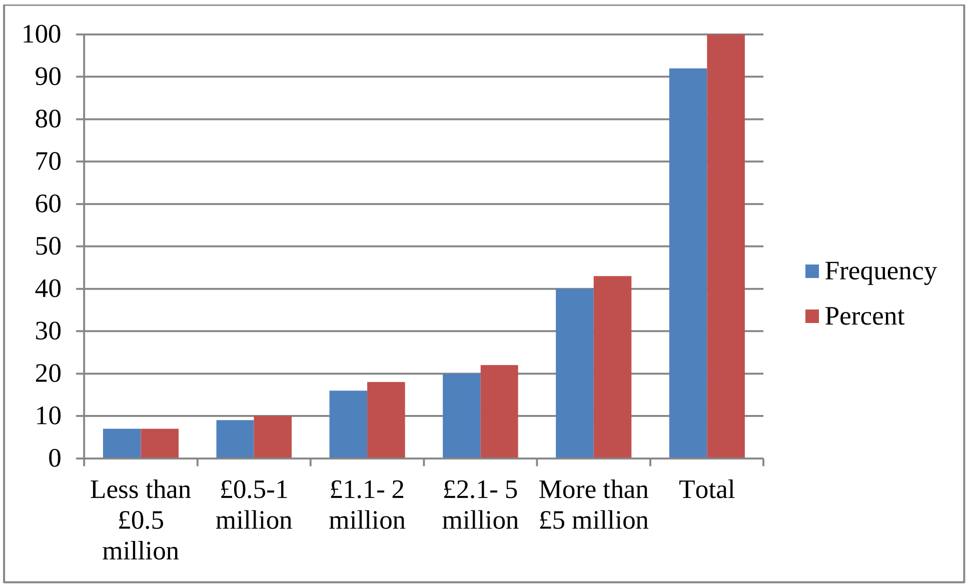


Figure 6. 4 Average company turn over

6.5 Testing Components of the Framework

The quantitative data generated through the questions in Sections B, C, D, E and F of the questionnaire (see Appendix F) was analysed using relevant techniques that helped in testing the conceptual framework. In order to achieve this, the framework was tested by assessing the findings across its components. These are discussed below.

6.5.1 Testing for "Negative and Positive Impacts"- Impact of Lean Construction Techniques on Safety

Section B of the questionnaire measures the impact of Lean Construction techniques on safety on construction sites. The median measures are presented in Table 6.1. The median indicates that the respondents believe all the Lean Construction techniques presented in the questionnaire have positive impact on safety (rating = 4) with the exception of 'Just-in-time' technique which has neutral impact (rating = 3). This means that based on their views none of the technique has a negative impact on safety. This validates the qualitative study findings in respect to the negative impact of Lean techniques on safety.

The ranking indices of the Lean techniques were computed using the procedures described in Section 4.8.4.2. The ranking showed that “Clean workplace” which is a technique under 5S (house-keeping) has the most positive potential impact on safety with a ranking index of 0.83. This is followed by “Open communication between management and workers” which is part of daily huddle meetings and then “pre-task hazard analysis” which is part of the Last Planner System. On the other hand, “Just-in-time” has the least positive potential impact on safety.

Table 6. 1 Descriptive statistics of the Potential Impact of Lean Construction Techniques on Safety on Construction Site

	Lean Construction Techniques	**Median**	**R.I**	**Ranks**	**Rwg**
i.	Clean workplace	4	0.839	1	0.90
ii.	Open communication between management and workers	4	0.828	2	0.87
iii.	Pre-task hazard analysis	4	0.826	3	0.89
iv.	Materials and plants organisation	4	0.817	4	0.92
v.	Visual inspection	4	0.798	5	0.89
vi.	Weekly work planning	4	0.789	6	0.84
vii.	Workers involvement in task planning	4	0.787	7	0.83
viii.	Visual Safety borders and demarcation	4	0.787	7	0.86
ix.	Coordination of workers and simultaneous activities	4	0.787	7	0.86
x.	Offsite fabrication	4	0.787	10	0.83
xi.	Correlating Tasks with workers’ ability	4	0.778	11	0.82
xii.	Critical Tasks planning	4	0.776	12	0.86
xiii.	Standardisation	4	0.776	12	0.87
xiv.	Integrated supply chain (supplier involvement)	4	0.776	12	0.80
xv.	Visibility improvement	4	0.774	15	0.86
xvi.	Correlating work methods with workers’ skills	4	0.774	15	0.84
xvii.	Safety signs and labels	4	0.770	17	0.84
xviii.	Collaborative planning	4	0.767	18	0.81
xix.	Equipment failure/Hazards warning and alert systems	4	0.764	19	0.85
xx.	Workers involvement in daily huddle meetings (DHM)	4	0.746	20	0.75
xxi.	Work methods illustration	4	0.717	21	0.78
xxii.	Process mapping	4	0.713	22	0.77
xxiii.	Workers’ empowerment in assignment scheduling	4	0.711	23	0.79
xxiv.	Just-in-time	3	0.628	24	0.67

An inter-rater agreement test was carried out to evaluate the extent to which the respondents make exactly the same judgement about the rated subjects (Mandrekar 2011). It checked the consistency in both where they agreed and disagreed. The level of agreement is considered acceptable if the value Rwg is ≥ 0.76. All the statements were found to have an acceptable Rwg values except the statement below:

i. Just-in-time has a neutral impact on safety.

Therefore, it can be concluded that the respondents consistently agree that all the Lean Construction techniques identified in this study have a positive impact on safety. However, there is no sufficient consensus among them on the fact that Just-in-time has a neutral impact on safety. This indicates that Just-in-time has either a positive impact or a negative impact on safety. However, the results of qualitative analysis in Section 6.5 indicates that Just-in-time leads to less site congestion and less congestion reduces the chance of accidents occurring on construction sites (HSE 2009, see Section 3.8.3). Therefore, it can be inferred that Just-in-time has a positive impact on safety. The results of this quantitative analysis validate findings in respect to the positive safety impact of the 24 Lean techniques.

A Chi-Square test was conducted on the response data of the Lean techniques in Table 6.1 in order to justify that the sample is a representation of the population once the differences between the expected and observed frequencies are significant (as discussed in Section 4.8.4.3.1). The Chi-Square results presented in Table 6.2 show that there are differences between the observed and expected responses (null hypothesis). The statistics in Table 6.3 show that the differences are significant ($p < 0.01$). Hence, there is enough evidence to reject the null hypothesis and the sample can therefore be inferred to be a representation of the population.

Table 6. 2 Frequencies of responses on the potential Impact of Lean Construction Techniques on Safety on Construction Site

	Workers' empowerment		**Correlate work methods with skills**		**Pre-task hazard analysis**		**Workers' involvement in task planning**		**Correlating Tasks with ability**		**Weekly work planning**	
	Observed	Expected	Observed	Expected	Observed	Expected	Observed	Expected	Observed	Expected	Observed	Expected
Very Negative	3	18.4	1	18.4	0	18.4	1	18.4	0	18.4	0	18.4
Negative	5	18.4	5	18.4	3	18.4	5	18.4	7	18.4	4	18.4
Neutral	34	18.4	15	18.4	15	18.4	14	18.4	17	18.4	21	18.4
Positive	38	18.4	55	18.4	41	18.4	51	18.4	47	18.4	42	18.4
Very Positive	12	18.4	16	18.4	33	18.4	21	18.4	21	18.4	24	18.4
	Open communication		**DH Meetings**		**Coordinatn of workers**		**Process mapping**		**Critical Tasks planning**		**Collaborative planning**	
Very Negative	1	18.4	1	18.4	0	18.4	1	18.4	1	18.4	1	18.4
Negative	4	18.4	11	18.4	2	18.4	9	18.4	3	18.4	6	18.4
Neutral	12	18.4	23	18.4	26	18.4	33	18.4	22	18.4	20	18.4
Positive	39	18.4	34	18.4	40	18.4	35	18.4	46	18.4	45	18.4
Very Positive	36	18.4	23	18.4	24	18.4	14	18.4	20	18.4	20	18.4
	Just-in-time		**Work Methods illustration**		**Safety signs and labels**		**Visual Safety borders**		**Visibility improvement**		**Visual inspection**	
	Observed	Expected	Observed	Expected	Observed	Expected	Observed	Expected	Observed	Expected	Observed	Expected
Very Negative	7	18.4	1	18.4	0	18.4	0	18.4	0	18.4	0	18.4
Negative	18	18.4	8	18.4	4	18.4	3	18.4	3	18.4	1	18.4
Neutral	30	18.4	33	18.4	24	18.4	27	18.4	25	18.4	21	18.4
Positive	29	18.4	36	18.4	46	18.4	35	18.4	45	18.4	48	18.4
Very Positive	8	18.4	14	18.4	18	18.4	27	18.4	19	18.4	22	18.4
	Offsite fabrication		**Hazards alert system**		**Clean workplace**		**Plants' organization**		**Standardisation**		**Integrated supply**	
Very Negative	0	18.4	2	18.4	0	18.4	0	18.4	0	18.4	0	18.4
Negative	5	18.4	1	18.4	3	18.4	3	18.4	3	18.4	7	18.4
Neutral	22	18.4	24	18.4	11	18.4	12	18.4	23	18.4	22	18.4
Positive	38	18.4	47	18.4	43	18.4	51	18.4	48	18.4	38	18.4
Very Positive	26	18.4	16	18.4	35	18.4	26	18.4	18	18.4	25	18.4

Table 6. 3 Chi-Square statistics of the Impact of Lean on Safety on Construction Site

	Workers' empowerment	**Correlating work methods with skills**	**Pre-task hazard analysis**	**Workers' involvement in task planning**	**Correlating Tasks with ability**
Chi-Square	62.556	62.089	39.689	82.791	40.400
Asymp. Significance(p)	.000	.000	.000	.000	.000
	Weekly work planning	**Open comunicatn between mngt & workers**	**Workers' involvement in DH Meetings**	**Coordinatn of wrkrs & simultaneous actvts**	**Process mapping**
Chi-Square	31.945	39.857	11.637	31.066	52.742
Asymp. Significance(p)	.000	.000	.009	.000	.000
	Critical Tasks planning	**Collaborative planning**	**Just-in-time**	**Work methods illustration**	**Safety signs and labels**
Chi-Square	74.110	65.648	28.222	53.560	38.275
Asymp. Significance(p)	.000	.000	.000	.000	.000
	Visual Safety borders and demarcation	**Visibility improvement**	**Visual inspection**	**Offsite fabrication**	**Equipment failure/ hazards alert system**
Chi-Square	27.110	40.044	45.876	24.933	79.222
Asymp. Significance(p)	.000	.000	.000	.000	.000
	Clean workplace	**Materials and plants' organisation**	**Standardisation**	**Integrated supply chain/ supplier involvmnt**	
Chi-Square	49.615	62.089	46.267	20.077	
Asymp. Significance(p)	.000	.000	.000	.000	

6.5.2 Testing the "Processes (Interaction Matrix)"- Potential Impact of Lean Construction Techniques in Reducing Accident Causations

The set of quantitative data collected under section C of the questionnaire measures the potential impact of Lean Construction techniques in the reduction of accident causations (see Appendix F) with a view to test the relationships collected in the "Processes (interaction matrix" component, in Table 6.13, of the conceptual framework. Respondents were asked to rate their level of agreement or disagreement with the statements that described the potential impacts of Lean Construction techniques in reducing accident causations. The categories of rating include 1 (Strongly disagree), 2 (Disagree), 3 (Neutral), 4 (Agree) and 5 (Strongly agree).

6.5.2.1 Workers- related Techniques

Table 7.4 shows the median of the ratings of the impact of workers related Lean Construction techniques in reducing accident causations on construction sites (see Section C in Appendix F). The table shows that most respondents agreed that all the workers-related Lean techniques could reduce accident causations (Median rating = 4).

An inter-rater agreement test was carried out to evaluate the extent to which the respondents make exactly the same judgement about the rated subjects (Mandrekar 2011). It checked the consistency in their rating. The level of agreement is considered acceptable if the value Rwg is ≥ 0.76. The statements below were found to have an acceptable Rwg values.

i. Workers' empowerment could reduce accident caused by organisational pressure
ii. Workers' empowerment could reduce accident caused by excessive stress
iii. Correlating work methods with workers' skills could reduce accident caused by excessive stress
iv. Workers involvement in task planning could reduce accident caused by lack of motivation
v. Coordination of workers and simultaneous activities could reduce accident caused by site congestion
vi. Correlating tasks with workers' ability could reduce accident caused by physical and mental inability.

Therefore, it can be concluded that the respondents consistently agree that all the workers-related Lean techniques could reduce accident causations.

Table 6. 4 Descriptive statistics of the Impact of Workers Related Techniques on Reducing Accidents Causations

	Empowermnt vs organisational pressure	Correlatin mthds with ability vs excsv stress	Corelating tasks and abilty vs inability	Empowerment vs excessive stress	Workers involvmnt in wrk plng vs motivatn	Coordntn of wrkrs & s/actvts vs congstn
Disagreemnt	6	5	2	7	10	5
Neutrality	14	14	17	20	20	19
Agreement	72	73	73	65	62	68
Median	4	4	4	4	4	4
Rwg	0.83	0.86	0.88	0.80	0.76	0.85

A chi-square test was conducted to justify that the sample is a representation of the population once the differences between the expected and observed frequencies are significant. The null hypothesis states that responses for the rating categories are equally distributed. The results of Chi-Square test presented in Table 6.5 show that there are differences in the observed and expected responses (null hypothesis). The test statistics in Table 7.6 show that the differences between the observed and expected are significant ($p < 0.01$). Hence, there is enough evidence to reject the null hypothesis and the sample can therefore be inferred to be a representation of the population.

Table 6. 5 Frequencies of responses on the Impact of Workers Related Techniques on Reducing Accidents Causations

	Empowermnt vs organisational pressure		**Correlatin mthds with ability vs excsv stress**		**Corelating tasks and ability vs mental and physical inability**	
	Observed	Expected	Observed	Expected	Observed	Expected
Strongly Disagree	2	18.4	1	18.4	0	18.4
Disagree	4	18.4	4	18.4	2	18.4
Neutral	14	18.4	14	18.4	17	18.4
Agree	48	18.4	51	18.4	52	18.4
Strongly Agree	24	18.4	22	18.4	21	18.4
	Empowerment vs excessive stress		**Workers involvmnt in work plng vs motivatn**		**Coordntn of workers & s/actvts vs congstn**	
	Observed	Expected	Observed	Expected	Observed	Expected
Strongly Disagree	0	18.4	3	18.4	0	18.4
Disagree	7	18.4	7	18.4	5	18.4
Neutral	20	18.4	20	18.4	19	18.4
Agree	46	18.4	39	18.4	39	18.4
Strongly Agree	19	18.4	23	18.4	29	18.4

Table 6. 6 Chi-Square statistics on the Impact of Workers Related Techniques on Reducing Accidents Causations

Test Statistics			
	Empowermnt vs organisational pressure	Correlatin mthds with ability vs excsv stress	Corelating tasks and abilities vs mental and physical inability
Chi-Square	76.527	89.824	55.593
Asymp. Significance(p)	.000	.000	.000
	Empowerment vs excessive stress	Workers involvmnt in wrk plng vs motivatn	Coordntn of wrkrs & s/actvts vs congstn
Chi-Square	35.989	44.330	29.396
Asymp. Significance(p)	.000	.000	.000

6.5.2.2 Planning- related Techniques

The median rating of the potential impact of planning related techniques in reducing accident causations are presented in Table 6.7 (see Section C in Appendix F). The median ratings of 4 for all the techniques indicated that most respondents agreed that all the planning related techniques could reduce accident causations on construction sites.

An inter-rater agreement test was carried out to evaluate the extent to which the respondents make exactly the same judgement about the rated subjects (Mandrekar 2011). It checked the consistency in their rating. The level of agreement is considered acceptable if the value Rwg is ≥ 0.76. All the statements below were found to have Rwg ≥ 0.76

i. Weekly work planning could reduce accidents caused by poor site management.
ii. Weekly work planning could reduce accidents caused by poor planning and control.
iii. Collaborative planning could help in risks identification and reduction.
iv. Collaborative planning could help in better works planning.
v. Collaborative planning could help in identifying safer work methods.
vi. Collaborative planning could help in improving contractors' safety knowledge and awareness.
vii. Critical tasks planning could reduce accidents caused by poor planning.

Therefore, it can be concluded that the respondents consistently agree that planning-related Lean techniques could reduce accident causations.

Table 6. 7 Descriptive statistics of the Impact of Planning Related Techniques in Reducing Accidents Causations

	Weekly work planing vs poor site mngt	Weekly work planing vs poor planing control	Collaborative planing vs risks	Collaborative planning vs better wrks planning	Collaborative planning vs contractrs sfty knwl	Collaborative planning vs safer work methods	Critical Tasks planing vs poor planing & contrl
Disagreement	1	1	2	0	2	1	1
Neutrality	10	9	5	8	15	8	10
Agreement	81	82	84	84	75	83	81
Median	4	4	4	4	4	4	4
Rwg	0.93	0.95	0.93	0.96	0.89	0.95	0.93

A chi-square test was conducted to justify that the sample is a representation of the population once the differences between the expected and observed frequencies are significant. The null hypothesis states that responses for the rating categories are equally distributed. The frequencies of responses from Chi-Square test presented in Table 6.9 show that there are differences in the observed and expected responses (null hypothesis) on the rating categories. Table 6.8 shows that the differences between the observed and expected responses are significant ($p < 0.01$). Hence, there is enough evidence to reject the null hypothesis and the sample can therefore be inferred to be a representation of the population.

Table 6. 8 Chi-Square statistics on the Impact of Planning Related Techniques in Reducing Accident Causations

	Weekly work planing vs poor site mngt	Weekly work planing vs poor planing control	Collaborative planing vs risks	Collaborative planning vs better wrks planning
Chi-Square	57.264	24.154	65.703	27.978
Asymp. Significance(p)	.000	.000	.000	.000
	Collaborative planning vs contractrs sfty knwl	Collaborative planning vs safer work methods	Critical Tasks planing vs poor planing & contrl	
Chi-Square	44.933	34.967	54.451	
Asymp. Significance(p)	.000	.000	.000	

6.5.2.3 Tasks- related Techniques

Table 6.10 presents the median of the responses on the potential impact of tasks related techniques in reducing accident causations (see Section C in Appendix F). The table shows that most respondents agreed that all the tasks related techniques could reduce accident causations (median rating = 4).

An inter-rater agreement test was carried out to evaluate the extent to which the respondents make exactly the same judgement about the rated subjects (Mandrekar 2011). It checked the consistency in their rating. The level of agreement is considered acceptable if the value Rwg is ≥ 0.76. The statements below were found to have an acceptable Rwg values:

i. Offsite manufacturing could reduce accidents caused by site hazards
ii. Pre-task hazard analysis could reduce workers exposure to risks
iii. Work methods illustration could reduce accidents caused by lack of knowledge
iv. Work methods illustration could reduce accidents caused by procedural issues
v. Offsite manufacturing could reduce high risk activities.

Table 6. 9 Frequencies of responses on the Impact of Planning Related Techniques in Reducing Accident Causations

	Weekly work planing vs poor site mngt		**Weekly work planing vs poor planing control**		**Collaborative planing vs risks**		**Collaborative planning vs better wrks planing**	
	Observed	Expected	Observed	Expected	Observed	Expected	Observed	Expected
Strongly Disagree	0	18.4	0	18.4	0	18.4	0	18.4
Disagree	1	18.4	1	18.4	2	18.4	0	18.4
Neutral	10	18.4	9	18.4	5	18.4	8	18.4
Agree	46	18.4	46	18.4	44	18.4	46	18.4
Strongly Agree	35	18.4	36	18.4	40	18.4	38	18.4
	Collaborative planning vs contractrs sfty knwl		**Collaborative planning vs safer work methods**		**Critical Tasks planing vs poor planing & contrl**			
	Observed	Expected	Observed	Expected	Observed	Expected		
Strongly Disagree	0	18.4	0	18.4	0	18.4		
Disagree	2	18.4	1	18.4	1	18.4		
Neutral	15	18.4	8	18.4	10	18.4		
Agree	44	18.4	54	18.4	43	18.4		
Strongly Agree	31	18.4	29	18.4	38	18.4		

Therefore, it can be concluded that the respondents consistently agree that all the task-related Lean techniques could reduce accident causations.

Table 6. 10 Descriptive statistics of Impact of Tasks Related Techniques in Reducing Accident Causations

	Work methods illustration vs lack of knowledge	**Work methods illustration vs lack of procedures**	**Offsite manufacturing vs high risk activities**	**Offsite manufacturing vs site hazards**	**Pre-task hazard analysis vs risk**
Disagreement	5	9	1	1	1
Neutrality	17	31	13	8	7
Agreement	70	52	78	83	84
Median	4	4	4	4	4
Rwg	0.84	0.77	0.92	0.94	0.96

A Chi-Square test was conducted on the response data of the Lean techniques in Table 6.10 in order to justify that the sample is a representation of the population once the differences between the expected and observed frequencies are significant. The frequencies of the responses on the rating categories for the tasks related techniques, presented in Table 6.11, show that there are differences between the observed and expected responses (null hypothesis). The Chi-Square test results in Table 6.12 show that the differences between the observed and expected responses are significant ($p < 0.01$). Hence, there is enough evidence to reject the null hypothesis and the sample can therefore be inferred to be a representation of the population.

Table 6. 11 Frequencies of responses on the Impact of Tasks Related Techniques in Reducing Accident Causations

	Work mthds illustratn vs lack of knwldg		**Work mthds illustratn vs lack of procedures**		**Offsite manufacturing vs high risk actvts**	
	Observed	Expected	Observed	Expected	Observed	Expected
Strongly Disagree	0	18.4	1	18.4	0	18.4
Disagree	5	18.4	8	18.4	1	18.4
Neutral	17	18.4	31	18.4	13	18.4
Agree	44	18.4	34	18.4	35	18.4
Strongly Agree	26	18.4	18	18.4	43	18.4
	Offsite manufacturing vs site hazards		**Pre-task hazard analysis vs risk**			
	Observed	Expected	Observed	Expected		
Strongly Disagree	0	18.4	0	18.4		
Disagree	1	18.4	1	18.4		
Neutral	8	18.4	7	18.4		
Agree	39	18.4	45	18.4		
Strongly Agree	44	18.4	39	18.4		

Table 6. 12 Chi-Square statistics on the Impact of Tasks Related Techniques in Reducing Accident Causations

	Work mthds illustratn vs lack of knwldg	Work mthds illustratn vs lack of procedures	Offsite manufacturing vs high risk actvts	Offsite manufacturing vs site hazards	Pre-task hazard analysis vs risk
Chi-Square	33.791	43.011	49.562	63.154	27.516
Asymp. Significance(p)	.000	.000	.000	.000	.000

6.5.2.4 Workplace- related Techniques

Table 6.13 presents the median ratings of the responses on the potential impact of workplace related techniques in reducing accident causations (see Section C in Appendix F). The table shows that most respondents strongly agreed that ‘clean workplace’ could reduce site hazards and untidiness (median rating = 5).

An inter-rater agreement test was carried out to evaluate the extent to which the respondents make exactly the same judgement about the rated subjects (Mandrekar 2011). It checked the consistency in their rating. The level of agreement is considered acceptable if the value Rwg is ≥ 0.76. The statements below were found to have an acceptable Rwg values:

i. Clean workplace could reduce accidents caused by site hazards.
ii. Clean workplace could reduce accidents caused by untidy site.
iii. Materials and plants organisation could reduce accidents caused by site congestion.
iv. Clean workplace could reduce accidents caused by site congestion.
v. Materials and plants organisation could reduce accidents caused by falling objects.

Therefore, it can be concluded that the respondents consistently agree that all the workplace-related Lean techniques could reduce accident causations.

Table 6. 13 Descriptive statistics on the Impact of Workplace Related Techniques in Reducing Accident Causations

	Clean workplace vs site hazards	Clean workplace vs untidy site	Clean workplace vs congestion	Mtrls & plants organistn vs falling objects	Mrtls & plants organisatn vs site congest
Disagreement	2	0	3	1	2
Neutrality	2	3	12	10	5
Agreement	88	89	77	81	85
Median	5	5	4	4	4
Rwg	0.94	0.98	0.89	0.93	0.93

A Chi-Square test was conducted on the response data of the Lean techniques in Table 6.13 in order to justify that the sample is a representation of the population once the differences between the expected and observed frequencies are significant. The Chi-Square results presented in Table 6.14 show that there are differences between the observed and expected responses (null hypothesis) across the rating categories. The chi-square test results in Table 6.15 show that the differences between the observed and expected responses are significant ($p < 0.01$). Hence, there is enough evidence to reject the null hypothesis and the sample can therefore be inferred to be a representation of the population.

Table 6. 14 Frequencies of responses on the Impact of Workplace Related Techniques in Reducing Accident Causations

	Clean workplace vs site hazards		**Clean workplace vs untidy site**		**Clean workplace vs congestion**	
	Observed	Expected	Observed	Expected	Observed	Expected
Strongly Disagree	0	18.4	0	18.4	1	18.4
Disagree	2	18.4	0	18.4	2	18.4
Neutral	2	18.4	3	18.4	12	18.4
Agree	34	18.4	31	18.4	33	18.4
Strongly Agree	54	18.4	58	18.4	44	18.4
	Mtrls & plants organistn vs falling objects		**Mrtls & plants organisatn vs site congest**			
	Observed	Expected	Observed	Expected		
Strongly Disagree	0	18.4	0	18.4		
Disagree	1	18.4	2	18.4		
Neutral	10	18.4	5	18.4		
Agree	41	18.4	47	18.4		
Strongly Agree	40	18.4	38	18.4		

Table 6. 15 Chi-Square statistics on the Impact of Workplace Related Techniques in Reducing Accident Causations

	Clean workplace vs site hazards	Clean workplace vs untidy site	Clean workplace vs congestion	Mtrls & plants organistn vs falling objects	Mrtls & plants organisatn vs site congest
Chi-Square	85.396	51.714	82.132	54.099	70.451
Asymp. Significance(p)	.000	.000	.000	.000	.000

6.5.2.5 Communication- related Techniques

The median of the responses on the potential impact of communication related techniques in reducing accident causations are presented in Table 6.16 (see Section C in Appendix F). The table shows that most respondents agreed that all the communication related techniques could reduce accident causations (median rating = 4).

An inter-rater agreement test was carried out to evaluate the extent to which the respondents make exactly the same judgement about the rated subjects (Mandrekar 2011). It checked the consistency in their rating. The level of agreement is considered acceptable if the value Rwg is ≥ 0.76. The statements below were found to have adequate Rwg values.

i. Daily huddle meetings could help in risks' identification and reduction.
ii. Daily huddle meetings could reduce accidents caused by poor communication.
iii. Daily huddle meetings could help reduce accidents caused by lack of safety awareness.

Therefore, it can be concluded that the respondents consistently agree that all the communication-related Lean techniques could reduce accident causations.

Table 6. 16 Descriptive statistics of the Impact of Communication Related Techniques in Reducing Accident Causations

	Daily huddle meetings vs poor comunicatn	Daily huddle meetings vs H&S awareness	Daily huddle metings vs risk mngt
Disagreement	3	3	5
Neutrality	15	12	17
Agreement	74	77	70
Median	4	4	4
Rwg (Unmerged)	0.70	0.71	0.59
Rwg (Merged)	0.87	0.90	0.84

A Chi-Square test was conducted on the response data of the Lean techniques in Table 6.16 in order to justify that the sample is a representation of the population once the differences between the expected and observed frequencies are significant. The frequencies of responses for the rating categories, presented in Table 6.17, show that there are differences in the observed and expected responses (null hypothesis). The chi-square test results in Table 6.18 show that the differences between the observed and the expected responses are significant ($p < 0.01$). Hence, there is enough evidence to reject the null hypothesis and the sample can therefore, be inferred to be a representation of the population.

Table 6. 17 Frequencies of responses on the Impact of Communication- related Techniques in Reducing Accident Causations

	Daily huddle meetings vs poor comunicatn		**Daily huddle meetings vs H&S awareness**		**Daily huddle metings vs risk mngt**	
	Observed	Expected	Observed	Expected	Observed	Expected
Strongly Disagree	0	18.4	0	18.4	2	18.4
Disagree	3	18.4	3	18.4	3	18.4
Neutral	15	18.4	12	18.4	17	18.4
Agree	46	18.4	41	18.4	44	18.4
Strongly Agree	28	18.4	36	18.4	26	18.4

Table 6. 18 Chi-Square statistics of the Impact of Communication Related Techniques in Reducing Accident Causations

	Daily huddle meetings vs poor comunicatn	Daily huddle meetings vs H&S awareness	Daily huddle metings vs risk mngt
Chi-Square	42.758	46.363	64.330
Asymp. Significance(p)	.000	.000	.000

6.5.2.6 Visual Management Techniques

The descriptive statistics (median) of the responses on the impact of visual management techniques in reducing accident causations are presented in Table 6.19 (see Section C in Appendix F). The table shows that most respondents agreed that all the visual management techniques could reduce accident causations (median rating = 4). Similarly, most respondents neither agreed nor disagreed that ‘Safety signs and labels’ could reduce untidiness on the construction site (median rating = 3).

An inter-rater agreement test was carried out to evaluate the extent to which the respondents make exactly the same judgement about the rated subjects (Mandrekar 2011). It checked the consistency in their rating. The level of agreement is considered acceptable if the value Rwg is ≥ 0.76. The statements below were found to have an acceptable Rwg values.

i. Safety signs and labels could reduce accidents caused by human error
ii. Safety signs and labels could reduce accidents caused by poor communication
iii. Visual safety borders and demarcation could reduce accidents caused by human error
iv. Visibility improvement could reduce accidents caused by human error
v. Visibility improvement could reduce accidents caused by trip hazards

Therefore, it can be concluded that the respondents consistently agree that the visual management techniques listed above could reduce accident causations while the statement below has an inadequate Rwg value.

i. Safety signs and labels could reduce accidents caused by untidy site.

Though this relationship has not been reported in the literature, it was found from interviews held with Lean practitioners.

Table 6. 19 Descriptive statistics of the Impact of Visual Management Techniques in Reducing Accident Causations

	Safety signs and labels vs human error	Safety signs and labels vs poor comunicatn	Safety signs and labels vs untidy site	Visual Safety borders & demarcatn vs error	Visibility improvement vs trip hazards	Visibility improvement vs human error
Disagreement	10	5	22	5	0	10
Neutrality	24	22	34	14	14	18
Agreement	60	65	36	73	78	64
Median	4	4	3	4	4	4
Rwg	0.78	0.83	0.74	0.85	0.93	0.76

A Chi-Square test was conducted on the response data of the Lean techniques in Table 6.19 in order to justify that the sample is a representation of the population once the differences between the expected and observed frequencies are significant. The results of the Chi-Square test on the data of visual management techniques, presented in Table 6.20, show that there are differences between the observed and expected (null hypothesis) responses on the categories of rating. Table 6.21 shows that the differences between the observed and expected are significant ($p < 0.01$). Hence, there is enough evidence to reject the null hypothesis and the sample can therefore, be inferred to be a representation of the population.

Table 6. 20 Chi-Square statistics of the Impact of Visual Management Techniques in Reducing Accident Causations

	Safety signs and labels vs human error	**Safety signs and labels vs poor communication**	**Safety signs and labels vs untidy site**
Chi-Square	55.648	73.560	29.038
Asymp. Significance(p)	.000	.000	.000
	Visual Safety borders & demarcatn vs error	Visibility improvement vs trip hazards	
Chi-Square	66.747	13.604	
Asymp. Significance(p)	.000	.001	

Table 6. 21 Frequencies of responses on the Impact of Visual Management Techniques in Reducing Accident Causations

	Safety signs and labels vs human error		**Safety signs and labels vs poor comunicatn**		**Safety signs and labels vs untidy site**	
	Observed	Expected	Observed	Expected	Observed	Expected
Strongly Disagree	2	18.4	2	18.4	6	18.4
Disagree	6	18.4	3	18.4	16	18.4
Neutral	24	18.4	22	18.4	34	18.4
Agree	42	18.4	48	18.4	26	18.4
Strongly Agree	18	18.4	17	18.4	10	18.4
	Visual Safety borders & demarcatn vs error		**Visibility improvement vs trip hazards**			
	Observed	Expected	Observed	Expected		
Strongly Disagree	2	18.4	0	18.4		
Disagree	3	18.4	0	18.4		
Neutral	14	18.4	14	18.4		
Agree	40	18.4	42	18.4		
Strongly Agree	33	18.4	36	18.4		

6.5.2.7 Other Lean Construction Techniques

Table 6.22 shows that median of the responses on the potential impact of “other Lean Construction techniques” in reducing accident causations (see Section C in Appendix F). The table shows that most respondents agreed that all “Other Lean Construction techniques” could reduce accident causations (median rating = 4). Most respondents neither agreed nor disagreed that just-in-time technique could reduce site congestion (median rating = 3).

An inter-rater agreement test was carried out to evaluate the extent to which the respondents make exactly the same judgement about the rated subjects (Mandrekar 2011). It checked the consistency in their rating. The level of agreement is considered acceptable if the value Rwg is ≥ 0.76. The statements below were found to have an acceptable Rwg values.

i. Visual inspection could reduce accidents caused by poor supervision.
ii. Standardisation could improve safety through risk understanding and mitigation.
iii. Suppliers’ involvement could help in risks’ identification and reduction.
iv. Process mapping could help in better planning of works.
v. Suppliers’ involvement could reduce accidents caused by safer work methods.

Therefore, it can be concluded that the respondents consistently agree that the above Lean techniques could reduce accident causations while the statement below has an inadequate Rwg value.

i. Just-in-time could reduce accidents caused by site congestion

Table 6. 22 Descriptive statistics of the Impact of the “Other Lean Construction Techniques” in Reducing Accident Causations

	Visual inspection vs poor supervision	**Standardisatn vs risk understandin & mitigtn**	**Just-in-time vs site congestion**	**Suppliers involvemnt vs risk mngt**	**Suppliers involvemnt vs safer work mthds**	**Process mapping vs better planning of works**
Disagreement	4	7	19	8	7	3
Neutrality	13	25	32	22	25	25
Agreement	75	59	41	62	60	64
Median	4	4	3	4	4	4
Rwg	0.88	0.79	0.71	0.80	0.88	0.86

A Chi-Square test was conducted on the response data of the Lean techniques in Table 6.22 in order to justify that the sample is a representation of the population once the differences between the expected and observed frequencies are significant. The results of the Chi-Square test presented in Table 6.23 show that there are differences in the observed and expected (null hypothesis) responses on the rating categories. Table 6.24 shows the Chi-Square test statistics which indicate that the differences between the observed and expected are significant ($p < 0.01$). Hence, there is enough evidence to reject the null hypothesis and the sample can therefore be inferred to be a representation of the population.

Table 6. 23 Chi-Square statistics of the Impact of the "Other Lean Construction Techniques" in Reducing Accident Causations

	Visual inspection vs poor supervision	Standardisatn vs risk understandin & mitigtn	Just-in-time vs site congestion
Chi-Square	75.319	58.176	21.843
Asymp. Significance(p)	.000	.000	.000
	Suppliers involvemnt vs risk mngt	Suppliers involvemnt vs safer work mthds	Process mapping vs better planning of works
Chi-Square	24.400	40.462	69.778
Asymp. Significance(p)	.000	.000	.000

Table 6. 24 Frequencies of responses on the Impact of the "Other Lean Construction Techniques" in Reducing Accident Causations

	Visual inspection vs poor supervision		**Standardisatn vs risk understandin & mitigtn**		**Just-in-time vs site congestion**	
	Observed	Expected	Observed	Expected	Observed	Expected
Strongly Disagree	1	18.4	1	18.4	5	18.4
Disagree	3	18.4	6	18.4	14	18.4
Neutral	13	18.4	25	18.4	32	18.4
Agree	42	18.4	42	18.4	23	18.4
Strongly Agree	33	18.4	17	18.4	18	18.4
	Suppliers involvemnt vs risk mngt		**Suppliers involvemnt vs safer work mthds**		**Process mapping vs better planning of works**	
	Observed	Expected	Observed	Expected	Observed	Expected
Strongly Disagree	0	18.4	2	18.4	1	18.4
Disagree	8	18.4	5	18.4	2	18.4
Neutral	22	18.4	25	18.4	25	18.4
Agree	41	18.4	45	18.4	44	18.4
Strongly Agree	21	18.4	15	18.4	20	18.4

6.5.3 Drivers to Lean Construction Practice in Organisations

This section presents the measures of importance of factors that influence contracting organisations' decision to engage in Lean Construction practice (see Section D in Appendix F). Respondents were asked to rate their perceptions of the importance of the factors using the scale: 1 (Little Importance), 2 (Some Importance), 3 (Quite Important), 4 (Important) and 5 (Very Important).

The median and mode of the responses for each factor are presented in Table 6.25. The table shows that most respondents rated 11 out of the 16 factors as very important (modal rating = 5); 4 factors were rated as important (modal rating = 4) while 1 factor was rated as quite important (modal rating = 3). The factors considered to be the most important in influencing their decision to engage in Lean practice are to reduce project cost, reduce project duration, improve product and services quality, improve safety, improve productivity, improve competitiveness, improve efficiency, deliver value to clients, increase revenues and profits, economise resources, and eliminate wasteful activities. The factors that were of less importance are; to enhance company image, improve presentation of products and services, best practice and to become leading edge in practice.

The ranking showed that “improving productivity” is the most influential factor that drove the organisations to engage in Lean Construction practice with a ranking index of 0.89. This is followed by “improving safety”, “improving efficiency” and “delivery of value to clients”. On the other hand, “the government reports” has the least influence with a least ranking index of 0.65.

Table 6. 25 Descriptive Statistics of the Drivers to Lean Construction Practice in Organisations

Drivers to applying Lean Construction Techniques	**Median**	**Mode**	**R.I**	**Ranks**
a. Improve productivity	5	5	0.896	1
b. Improve Safety	5	5	0.890	2
c. Improve efficiency	5	5	0.880	3
d. Deliver value to clients	5	5	0.880	3
e. Improve product and services quality	4	5	0.863	5
f. Eliminate wasteful activities	4	5	0.863	5
g. Reduce project cost	4	5	0.852	7
h. Reduce project duration	4	5	0.852	7
i. Best practice	4	5	0.841	9
j. Economise resources	4	5	0.835	10
k. Become leading edge in practice	4	5	0.833	11
l. Increase revenues and profits	4	5	0.830	12
m. Improve competitiveness	4	5	0.826	13
n. Enhance company image	4	4	0.824	14
o. Improve presentation of products and services	4	4	0.787	15
p. Government reports	3	3	0.654	16

A Chi-Square test was conducted to justify that the sample is a representation of the population once the differences between the expected and observed frequencies are significant. The frequencies of the responses presented in Table 6.26 show that there are differences between the observed and expected (null hypothesis). The chi-square test results shown in Table 6.27 indicate that the differences between the observed and expected responses are significant ($p < 0.01$). Hence, there is enough evidence to reject the null hypothesis and the sample can therefore be inferred to be a representation of the population.

Furthermore, none of the drivers has a median or mode of 1 (little importance). This shows that all the factors are considered as drivers to applying Lean Construction techniques in the organisations. Thus, this validates the study findings in respect to the drivers to Lean Construction practice.

Table 6. 26 Frequencies of responses on the Drivers to Lean Construction Practice in Organisations

	Cost_drv		**Duration_drv**		**Quality_drv**		**HandS_drv**	
	Observed	Expected	Observed	Expected	Observed	Expected	Observed	Expected
Little importance	1	18.4	0	18.4	0	18.4	0	18.4
Some importance	0	18.4	3	18.4	1	18.4	2	18.4
Quite important	15	18.4	13	18.4	10	18.4	4	18.4
Important	34	18.4	33	18.4	40	18.4	36	18.4
Very important	42	18.4	43	18.4	41	18.4	49	18.4
	Productivity_drv		**Competition_drv**		**Image_drv**		**Presentation_drv**	
Little importance	0	18.4	2	18.4	2	18.4	3	18.4
Some importance	1	18.4	7	18.4	1	18.4	6	18.4
Quite important	4	18.4	11	18.4	17	18.4	15	18.4
Important	37	18.4	29	18.4	36	18.4	38	18.4
Very important	50	18.4	43	18.4	36	18.4	30	18.4
	Efficiency_drv		**Value_drv**		**Leaders_drv**		**Profit_drv**	
	Observed	Expected	Observed	Expected	Observed	Expected	Observed	Expected
Little importance	1	18.4	1	18.4	2	18.4	4	18.4
Some importance	1	18.4	4	18.4	4	18.4	1	18.4
Quite important	8	18.4	4	18.4	9	18.4	13	18.4
Important	32	18.4	31	18.4	39	18.4	33	18.4
Very important	50	18.4	52	18.4	38	18.4	41	18.4
	Economise_drv		**Bestpractise_drv**		**Govtreport_drv**		**Waste_drv**	
Little importance	1	18.4		18.4	5	18.4		18.4
Some importance	4	18.4	4	18.4	19	18.4	3	18.4
Quite important	12	18.4	8	18.4	31	18.4	10	18.4
Important	36	18.4	45	18.4	22	18.4	34	18.4
Very important	39	18.4	35	18.4	15	18.4	45	18.4

Table 6. 27 Chi-Square statistics of the Drivers to Lean Construction Practice in Organisations

Test Statistics				
	Cost_drv	**Duration_drv**	**Quality_drv**	**HandS_drv**
Chi-Square	44.783	43.478	55.043	76.957
Asymp. Significance(p)	.000	.000	.000	.000
	Productivity_drv	**Competition_drv**	**Image_drv**	**Presentation_drv**
Chi-Square	72.385	67.222	64.848	48.505
Asymp. Significance(p)	.000	.000	.000	.000
	Efficiency_drv	**Value_drv**	**Leaders_drv**	**Profit_drv**
Chi-Square	103.109	108.978	74.630	66.967
Asymp. Significance(p)	.000	.000	.000	.000
	Economise_drv	**Bestpractise_drv**	**Govtreport_drv**	**Waste_drv**
Chi-Square	68.396	51.462	18.615	51.043
Asymp. Significance(p)	.000	.000	.001	.000

6.5.4 Challenges to Lean Construction Practice in Organisations

This section presents the measures of frequency of occurrence or weight of the challenges that impede on Lean Construction practice in the organisations (see Section E in Appendix F). The categories of rating presented to respondents include 1 (Never), 2 (Seldom), 3 (Often), 4 (Frequent) and 5 (Always). The median and mode of the ratings for the challenges are presented in Table 6.28. The table shows that most respondents rated 9 out of the 12 challenges as often (modal rating = 3). These are high implementation cost, non-compliance with instructions, lack of Lean knowledge, lack of incentives, misconceptions about Lean, complexity, lack of cooperation, change to work approach, difficulty to understand, inadequate resources.

The ranking showed that “lack of Lean knowledge” is the biggest challenge facing Lean Construction practice in the organisations with a ranking index of 0.68. This is followed by “misconceptions about Lean”, “complexity” and “lack of cooperation”. On the other hand, “unsuitable organisational structure” is the least challenge to Lean Construction practice in the organisations with a ranking index of 0.55.

Table 6. 28 Descriptive statistics of the Challenges of Lean Construction Practice in Organisations

Challenges to applying Lean Construction Techniques	Median	Mode	R.I	Ranks
a. Lack of Lean knowledge	3	3	0.683	1
b. Misconceptions about Lean	3	3	0.665	2
c. Complexity	3	3	0.637	3
d. Lack of cooperation	3	3	0.633	4
e. Inadequate resources	3	3	0.626	5
f. Change to work approach	3	3	0.624	6
g. Lack of incentives	3	3	0.620	7
h. High implementation cost	3	3	0.613	8
i. Non-compliance with instructions	3	3	0.593	9
j. Difficulty to understand	3	3	0.591	10
k. Lack of government support	3	2	0.583	11
l. Unsuitable organisational structure	3	2	0.550	12

The frequencies of responses obtained from the Chi-Square test, presented in Table 6.29, show that there are differences between the observed and expected (null hypothesis) responses across the rating categories.

The chi-square test results in Table 6.30 indicate that the differences between the observed and expected responses for most of the challenges are significant at $p < 0.01$. The only exception is ‘lack of government support with $p = 0.039$ which is still less than 0.05 ($p < 0.05$). Hence, there is enough evidence to reject the null hypothesis and the sample can therefore be inferred to be a representation of the population.

Table 6. 29 Frequencies of responses on the Challenges of Lean Construction Practice in Organisations

	Cost_chlng		Non-compliance_chlng		Knowledge_chlng		Misconception_chlng	
	Observed	Expected	Observed	Expected	Observed	Expected	Observed	Expected
Never	4	18.4	6	18.4	4	18.4	2	18.4
Seldom	25	18.4	26	18.4	9	18.4	11	18.4
Often	33	18.4	31	18.4	33	18.4	40	18.4
Frequent	21	18.4	23	18.4	37	18.4	33	18.4
Always	9	18.4	6	18.4	9	18.4	6	18.4
	Complexity_chlng		**Cooperation_chlng**		**Incentives_chlng**		**Govtspprt_chlng**	
Never	6	18.4	3	18.4	8	18.4	12	18.4
Seldom	14	18.4	25	18.4	19	18.4	25	18.4
Often	39	18.4	28	18.4	28	18.4	24	18.4
Frequent	23	18.4	26	18.4	30	18.4	21	18.4
Always	10	18.4	10	18.4	7	18.4	10	18.4
	Culture_chlng		**Understanding_chln**		**Organisationstrc_chln**		**Resources_chlng**	
	Observed	Expected	Observed	Expected	Observed	Expected	Observed	Expected
Never	3	18.4	5	18.4	11	18.4	4	18.4
Seldom	18	18.4	23	18.4	33	18.4	21	18.4
Often	41	18.4	40	18.4	20	18.4	37	18.4
Frequent	25	18.4	19	18.4	24	18.4	19	18.4
Always	5	18.4	5	18.4	4	18.4	11	18.4

Furthermore, none of the challenges has a median or mode of 1 (never). This shows that all the factors are considered as challenges to applying Lean Construction techniques in the organisations. Thus, this validates the study findings in respect to the challenges of Lean Construction practice.

Table 6. 30 Chi-Square statistics of the Challenges of Lean Construction Practice in Organisations

	Cost_chlng	Non-compliance_chlng	Knowledge_chlng	Misconception_chlng
Chi-Square	29.165	28.111	49.824	61.253
Asymp. Significance(p)	.000	.000	.000	.000
	Complexity_chlng	**Cooperation_chlng**	**Incentives_chlng**	**Govtspprt_chlng**
Chi-Square	35.648	26.527	23.556	10.068
Asymp. Significance(p)	.000	.000	.000	.039
	Culture_chlng	**Understanding_chlng**	**Organisationstrc_chlng**	**Resources_chlng**
Chi-Square	49.111	44.220	25.222	31.802
Asymp. Significance(p)	.000	.000	.000	.000

6.5.5 Outcomes of Lean Construction Practice in Organisations

This section presents the measures of frequency of outcomes of Lean Construction practice in the organisations (see Section F in Appendix F). The median and mode of the ratings of the outcomes are presented in Table 6.31. The table shows that 9 out the 13 outcomes were mostly rated as often (modal rating = 3). These are reduction in project cost, reduction in project duration, improvement in product and services quality, improvement in safety, larger profits, greater predictability, improved competitiveness, increase in revenues, and improvement in resources efficiency.

The ranking showed that "improvement in productivity" is the most observed outcome of Lean Construction practice in the organisations with a ranking index of 0.73. This is followed by "improvement in safety", "clients' satisfaction" and "reduction in project cost". On the other hand, "poor safety" and "poor human resource management" are the least observed outcomes with ranking indices of 0.40 and 0.47 respectively. Furthermore, this validates the study findings in respect to the outcomes of Lean Construction practice.

Table 6. 31 Descriptive statistics of the Outcomes of Lean Construction Practice in Organisations

Outcomes of Lean Construction Organisations	Median	Mode	R.I	Ranks
a. Improve productivity	4.00	4	0.733	1
b. Improve Safety	4.00	3	0.724	2
c. Clients' satisfaction	4.00	4	0.722	3
d. Reduce project cost	3.00	3	0.680	4
e. Greater predictability	3.00	3	0.674	5
f. Improve product and services quality	3.00	3	0.672	6
g. Improve resources efficiency	3.00	3	0.661	7
h. Improved competitiveness	3.00	3	0.659	8
i. Reduce project duration	3.00	3	0.657	9
j. Increase revenues and profits	3.00	3	0.617	10
k. Larger profits	3.00	3	0.609	11
l. Poor human resource management	2.00	2	0.4723	12
m. Poor Safety	2.00	2	0.402	13

The results of Chi-Square test on the responses, presented in Table 6.32, show that there are differences between the observed and expected (null hypothesis). The Chi-Square test statistics in Table 6.33 show that the differences between the observed and the expected are significant at $p < 0.01$. Hence, there is enough evidence to reject the null hypothesis and the sample can therefore, be inferred as a representation of the population.

Table 6. 32 Chi-Square statistics of the Outcomes of Lean Construction Practice in Organisations

	Cost_OP	Duration_OP	Quality_OP	ImproveHnS_OP
Chi-Square	40.813	26.778	61.473	19.778
Asymp. Significance(p)	.000	.000	.000	.000
	Productivity_OP	Profits_OP	PoorHRM_OP	Clientsatisfctn_OP
Chi-Square	14.099	29.111	40.264	61.033
Asymp. Significance(p)	.003	.000	.000	.000
	Predictability_OP	Competition_OP	Profit_OP	PoorHnS_OP
Chi-Square	25.378	54.889	47.889	57.011
Asymp. Significance(p)	.000	.000	.000	.000
	Efficiency_OP			
Chi-Square	19.956			
Asymp. Significance(p)	.000			

Table 6. 33 Frequencies of responses on the Outcomes of Lean Construction Practice in Organisations

	Cost_OP		**Duration_OP**		**Quality_OP**		**ImproveHnS_OP**	
	Observed	Expected	Observed	Expected	Observed	Expected	Observed	Expected
Never	3	18.4	2	18.4	1	18.4	0	18.4
Seldom	11	18.4	21	18.4	11	18.4	10	18.4
Often	36	18.4	30	18.4	46	18.4	34	18.4
Frequent	30	18.4	27	18.4	22	18.4	29	18.4
Always	12	18.4	12	18.4	12	18.4	19	18.4
	Productivity_OP		**Profits_OP**		**PoorHRM_OP**		**Clientsatisfctn_OP**	
Never	0	18.4	6	18.4	18	18.4	3	18.4
Seldom	8	18.4	21	18.4	35	18.4	6	18.4
Often	32	18.4	37	18.4	29	18.4	27	18.4
Frequent	35	18.4	19	18.4	8	18.4	44	18.4
Always	17	18.4	9	18.4	2	18.4	12	18.4
	Predictability_OP		**Competition_OP**		**Profit_OP**		**PoorHnS_OP**	
	Observed	Expected	Observed	Expected	Observed	Expected	Observed	Expected
Never	0	18.4	1	18.4	5	18.4	30	18.4
Seldom	13	18.4	14	18.4	16	18.4	42	18.4
Often	43	18.4	41	18.4	43	18.4	12	18.4
Frequent	25	18.4	29	18.4	22	18.4	5	18.4
Always	11	18.4	7	18.4	6	18.4	3	18.4
	Efficiency_OP							
Never	0	18.4						
Seldom	17	18.4						
Often	42	18.4						
Frequent	21	18.4						
Always	12	18.4						

6.5.6 Spearman's Correlations of Drivers and Outcomes of Lean Construction Practice

The application of Lean practice in the organisations was driven by the 16 factors mentioned in table 6.25 above. The purpose of engaging in Lean Construction practice is to have an outcome that satisfies these drivers. A Spearman's rank correlation test was conducted on key factors like cost, time, quality, safety, productivity, efficiency and value delivery, to check if there is a correlation between these drivers and outcomes of Lean Construction practice. This checks if the outcome (score on results) meets the demand (drivers and purpose of application) with respect to these 8 factors.

The results of the Spearman's rank correlation test conducted on the 8 major drivers and outcomes of Lean Construction practice are shown in Table 6.34. The table shows that there are weak correlations between the tested drivers and outcomes as their correlation coefficients are lower than 0.5. However, the non-zero correlation coefficients indicate that there is an association between the drivers and outcomes of Lean Construction practice. Furthermore, the significances of the correlation coefficients for 'Value', 'Productivity' and 'Quality' at 0.01, 0.01 and 0.05 respectively indicate that their respective correlations are valid.

Table 6. 34 Spearman's Correlation Coefficients of Drivers and Outcomes of Lean Construction Practice

	Correlation coefficients (r)	**Significance (p)**
Cost Driver & Cost Output	0.199	0.059
Duration Driver & Duration Output	0.138	0.195
Quality Driver & Quality Output	0.241*	0.021
Safety Driver & Safety Output	0.179	0.91
Productivity Driver & Productivity Output	0.295**	0.005
Competition Driver & Competition Output	0.092	0.391
Efficiency Driver & Efficiency Output	0.035	0.740
Value Driver & Value Output	0.353**	0.001

** Correlation is significant at 0.01 level (99% level of significance)

* Correlation is significant at 0.05 level (95% level of significance)

This shows that the outcome on these 8 factors have still not reached the desired level. Though they have a high priority and importance in driving the companies to engage in Lean

Construction practice, Lean Construction practice got a low score in terms of achieving the expected outcome on the 8 factors. However, the positive correlation shows that there are some improvements on all the 8 factors especially on value delivery, productivity and quality of products and services.

6.6 Summary

The descriptive statistical analysis of the impact of Lean Construction techniques on safety on construction site indicates that the respondents believe that all the Lean Construction techniques presented in the questionnaire have positive impact on safety (rating = 4) with the exception of ‘just-in-time’ technique which has neutral Impact (rating = 3). This means that based on their views none of the technique has a negative impact on safety. However, to have confidence in accepting their views, an inter-rater agreement test was conducted, to check the level of consensus among the respondents, using R statistical software. The results showed that the respondents consistently agree that all the Lean Construction techniques identified in the study have a positive impact on safety. However, there is no adequate consensus among them on the fact that “just-in-time has a neutral impact on safety”. This further validates findings in respect to the positive safety impact of the Lean techniques.

The ranking showed that “clean workplace” which is a technique under 5S (house-keeping) has the most positive potential impact on safety with a ranking index of 0.83. This is followed by “open communication between management and workers” which is part of daily huddle meetings and then “pre-task hazard analysis” which is part of the Last Planner System. On the other hand, “Just-in-time” was found to have the least positive potential impact on safety, according to the respondents, with a least ranking index of 0.62.
The Chi-Square test conducted to justify that the sample is a representation of the population showed that there are differences between the observed and expected responses. The results also showed that the differences are significant ($p < 0.01$). This implied that there was enough evidence to reject the null hypothesis. Similar results occurred across the whole study.

The second part of the questionnaire measured the potential impact of Lean Construction techniques in the reduction of accident causations. The median and mode of the ratings of the potential impact of all the Lean Construction techniques in reducing accident causations on construction sites were determined. However, to have confidence in accepting their views, an inter-rater agreement test was conducted, to check the level of consensus among the respondents, using R statistical software. The single-item inter-rater agreement (Rwg) indices of all the statements were determined. Based on the 10000 simulations, only statements with Rwg values $\geq$ 0.76 have evidence of consensus and adequate agreement among the respondents, and hence considered as valid relationships in this research.

All the statements on workers-related Lean techniques, planning-related Lean techniques, task-related Lean techniques and communication-related Lean techniques were found to have Rwg values $\geq$ 0.76 indicating that they could reduce accident causations. Similarly, all the statements on visual management techniques were found to have Rwg values $\geq$ 0.76 with the exception of:

i. Safety signs and labels could reduce accidents caused by untidy site

Furthermore, with the exception of the statement "just-in-time could reduce accidents caused by site congestion", all the statements on Lean techniques categorised as "Other Lean techniques", were found to have Rwg values $\geq$ 0.76 on a modal rating of 4, indicating that they could reduce accident causations. This validates the findings in respect to 36 out of the 38 relationships tested. However, the other 2 relationships were also found from interaction with Lean practitioners (see Section 5.5, p100).

An analysis of the organisations' purpose or drivers for engaging in Lean Construction practice was carried out. The study found that improving productivity, safety, and efficiency are the most important factors that influenced the organisations to engage in Lean Construction practice. This invariably means they are among the major purposes of Lean Construction practice in the organisations. The other major purposes are to reduce project cost, reduce project duration, improve product and services quality, improve competitiveness, deliver value to clients, increase revenues and profits, economise resources and elimination of wasteful activities. Despite its popularity, the factor that least influenced their decision is government reports like the Sir John Egan's report that recommended application of Lean thinking in the construction industry. The quantitative study results further validates the factors identified as drivers to Lean Construction practice in the qualitative study.

In order to achieve a successful application of the Lean Construction techniques mentioned above in promoting safety, the challenges facing these organisations have to be identified and addressed. An analysis of the challenges facing Lean Construction practice in the organisations was carried out. Lack of Lean Construction knowledge was found to be the biggest challenge facing Lean Construction practice in the organisation, which was followed by misconception about Lean and its complexity. The least challenge facing the organisations was unsuitable organisational structure to support Lean Construction practice. The quantitative study results further validates the factors identified as the challenges facing Lean Construction practice in the qualitative study.

A number of studies argued that the application of Lean principles in the construction industry can expose the workers to poor safety situations. The application of the lean principles was also associated with poor human resource management. However, this study found that improvements in productivity, safety and clients' satisfaction are the most experienced outcomes of Lean Construction practice in the organisations, whereas poor safety and poor human resource management are the least experienced outcomes of Lean Construction practice. Other positive outcomes often experienced are reduction in project cost, reduction in project duration, improvement in product and services quality, improvement in productivity, larger profits, greater predictability, improved competitiveness, increase in revenues, and improvement in resources efficiency. The quantitative study results further validates the factors identified as the outcomes of Lean Construction practice in the study.

A Spearman's rank correlation test was conducted to check if the outcome of Lean Construction practice correlates with the purpose of engaging in Lean practice in the organisations. It was carried out to determine whether the results meet the demand (drivers and purpose of application) with respect to factors like cost, time, quality, safety, productivity, efficiency and value delivery. Though they are positive, the correlation coefficients are lower than 0.5, indicating that there are weak correlations between the tested drivers and outcomes. This shows that the outcome on these 8 factors have not reached the desired level, which is also reflected in the organisations' experience of outputs below the desired level.

Having tested the different components of the framework, the fourth research objective has now been addressed. Based on the qualitative and quantitative study findings, the next chapter presents the integrated framework.

CHAPTER 7: AN INTEGRATED FRAMEWORK FOR UTILISING LEAN STRATEGIES FOR PROMOTING SAFETY ON CONSTRUCTION SITES

7.0 Introduction

Pursuant to objective five of this research and the findings from the previous chapters, this chapter presents the outcome of the research. It is discussed as an integrated framework for utilising Lean Construction techniques to promote safety practices on the UK construction sites. The chapter commences with the need for improvement in safety practices on UK construction sites, the application of Lean Construction techniques and the consequences on safety.

7.1 Towards Research Outcome

7.1.1 Improvement in safety

The literature discussions in (Chapters 1 and 2) established that safety practices on the UK construction sites are poor. Chapter two in particular demonstrated that over 50 deaths occur annually on construction sites in the UK as result of poor safety practices. A large amount of resources in terms of human, financial and time is also wasted due to accidents on construction sites. Current strategies adopted to address accidents on construction sites have not yielded expected results. This has therefore culminated in the search for alternative strategies to improve safety performance. Though it has been suggested that Lean Construction practices could improve safety on construction sites, the practices have not been fully explored for that purpose due to lack of empirical evidence (Chapter 3). It was to this end that the research was directed and was aimed at investigating the relationship between Lean Construction techniques and safety with a view to developing a framework by which Lean Construction techniques could be used to improve safety on the UK construction sites.

7.1.2 Lean Construction Principles and their applications

The Lean Construction principles were identified and discussed in Chapter 3. The chapter presented sixteen Lean Construction principles. These are: value identification; value stream; value stream flow; customer pull; perfection; continuous improvement; variability reduction;

reduction in cycle times; reduction in procedures; simplicity; focus control on the complete process; flow management; benchmarking; output flexibility; and process transparency, waste elimination; and workflow reliability. The first five principles are general lean thinking principles, which are applicable across industries while the other principles were noted to be more suitable for the construction industry. The chapter further established that interaction of these lean thinking principles generate Lean Construction tools. The chapter identified seven Lean Construction tools, which were relevant to safety. These are: Last Planner System; Visual management; Daily Huddle Meetings; 5S (House-keeping); 5Whys (root cause analysis); First Runs Studies; and Error-proofing (Chapter 3; Table 3.3, p53). Four additional Lean Construction tools with safety relevance were, however, identified following discussions with industry experts. These are: integrated supply chain; offsite fabrication; process mapping; collaborative planning; and standardisation (chapter 5). On the basis of these eleven tools, twenty two techniques were generated and their impacts interrogated. These are labeled as L1 – L22 (Table 5.12, p120).

The tools identified from the literature were used to generate fifteen techniques relevant to safety on construction sites. For instance, under Last Planner System, workers' empowerment in assignment scheduling (L1), correlating work methods with workers' skills (L2), correlating tasks with workers' ability (L3), pre-task hazard analysis (L4), weekly work planning (L5), and workers involvement in task planning (L16) were generated. Those under the Visual management were safety signs and labels (L10), visual safety borders and demarcations (L11), and visibility improvement (L12). Similarly, those under First run studies were critical tasks planning (L8) and work methods' illustration (L9). Clean workplace (L14) and material and plants' organisation (L14) were also generated under 5S (house-keeping). Only one technique; visual inspection (L13) was generated under EP tool. Finally those under the DHM are coordinating workers and simultaneous activities (L6) and open discussion between workers and management (L7).

Chapters two and three also noted that these Lean Construction techniques have linkage with sixteen safety issues on construction sites. These are labeled as S1-S16 (see Table 3.4, p56). The linkage between the Lean Construction techniques and nine of the sixteen safety issues were further confirmed based on findings from the interactions with industrial experts (see chapter 5). The interaction with industrial experts also revealed four additional safety issues that could be addressed by Lean Construction techniques. These are labeled as S17-S20 (chapter 5; Table 5.12, p120).

7.1.3 The Link between Lean Construction Techniques and Safety Issues

The study particularly in its Chapter five established that the Lean Construction techniques in general have positive influence on safety issues on construction sites in the UK. In other words, the Lean Construction techniques could be used to address safety issues on construction sites within the context of this study. Based on this, the conceptual framework was amended and redefined in Chapter five. The validity of these relationships, as well as other components of the conceptual framework, was tested using the quantitative study reported in Chapter six. The study found that different safety issues are addressed by one or more distinct Lean Construction techniques. Table 8.1 gives details on the individual safety issues on construction sites, and the Lean Construction techniques that can be used to address them.

These are summarised in the form of a Matrix presented by Table 7.2. The matrix shows a total of 38 areas of possible interaction between Lean Construction techniques and safety. Across the table are the Lean Construction techniques labeled L1-L22 while lower in the table are the safety issues labeled S1-S20.

Table 7. 1 Lean Construction tools and techniques relevant to Safety issues

Safety Issues	Lean Construction Technique (L)
S1. Tripping	Visibility improvement
S2. Excessive stress	Workers' empowerment in assignment scheduling (LPS)
	Correlating work methods with workers' skills (LPS)
S3. Poor supervision	Visual inspection (EP)
S4. Poor planning	Weekly work planning (LPS)
	Critical task planning (FRS)
	Process mapping
	Collaborative planning
S5. Falling objects	Materials and plants organisation (5S)
S6. Organisational pressure	workers empowerment in assignment scheduling (LPS)
S7. Poor communication	Workers' involvement in DH meetings
	Safety signs and labels (IV)
S8. Site hazards (eg dust, noise)	Clean workplace (5S)
	Offsite fabrication
S9. Human/ Judgement error	Safety signs and labels (IV)
	Visibility improvement (IV)
	Visual safety borders and demarcation (IV)
S10. Risk identification & reduction	Pre-task hazard analysis (LPS)
	Daily huddle meetings
	Collaborative planning
	Integrated supply chain
	Standardisation
S11. Lack of knowledge to read work method statements	Work methods illustration (FRS)
S12. Lack of safety awareness	Daily huddle meetings
	Collaborative planning
S13. Physical and mental inability	Correlating work methods with workers' skills (LPS)
S14. Site congestion	Coordinating workers and simultaneous activities (LPS)
	Materials and plants organisation (5S)
	Clean workplace (5S)
S15. Untidy site	Clean workplace (5S)
S16. Non-compliance with Procedures	Work methods illustration (FRS)
S17. High risk activities	Offsite fabrication
S18. Lack of motivation	Workers involvement in task planning (LPS)
S19. Poor work methods	Collaborative planning
	Integrated supply chain
S20. Poor site management	Weekly work planning (LPS)

Table 7. 2 Potential Interaction Matrix of Lean Construction Techniques and Safety issues

	Workers' empowerment in assignment Scheduling	Correlating work methods with workers' skills	Correlating tasks with workers' ability	Pre-task hazard analysis	Weekly work planning	Coordinating workers and simultaneous activities	Daily huddle meetings	Critical tasks planning	Work methods' illustration	Safety signs and labels	Visual safety borders and demarcations	Visibility improvement	Visual inspection	Clean workplace	Material and plants' organisation	Workers involvement in task planning	Process Mapping	Collaborative planning	Just-in-time	Standardisation	Offsite fabrication	Integrated supplychain
Safety issues/ Onsite accident causations	L1	L2	L3	L4	L 5	L6	L7	L8	L9	L 10	L11	L12	L13	L14	L15	L16	L 17	L 18	L 19	L 20	L 21	L22
S1. Tripping												√										
S2. Excessive stress	√	√																				
S3. Poor supervision													√									
S4. Poor planning					√			√									√	√				
S5. Falling objects															√							
S6. Organisational pressure	√																					
S7. Poor communication							√			√												
S8. Site hazards (eg dust, noise)														√							√	
S9. Human/ Judgement error										√	√	√										
S10. Risk identificatn & reduction				√			√											√		√		√
S11. Lack of knowledge									√													
S12. Lack of safety awareness							√											√				
S13. Physical and mental inability			√																			
S14. Site congestion						√								√	√				√			
S15. Untidy site										√				√								
S16. Procedural issues									√													
S17. High risk activities																					√	
S18. Lack of motivation																√						
S19. Poor work methods									√									√				√
S20. Poor site management					√																	

7.1.4 Challenges

The study, however, noted that the application of the Lean Construction techniques to address safety issues on construction sites could be affected by a number of challenges, which could reduce their effectiveness. These challenges were identified as: the difficulty in changing employees' working culture, lack of long term forecast and investment, long implementation time, high cost of implementation, low effort to learn, misconceptions about Lean, high expectations from management, non-compliance with instructions, lack of Lean knowledge, complexity, lack of cooperation and lack of incentives. However, the quantitative study found that the biggest challenges are lack of Lean Construction knowledge, misconception about Lean and its complexity while the least is unsuitable organisational structure to support Lean Construction practice. This signifies that steps must be taken to manage these challenges to achieve the overall benefit from implementation of Lean Construction techniques.

7.1.4 Strategies for Overcoming to the Challenges

The challenges have to be addressed in order to realise the targeted benefits. There are different ways of managing the challenges to Lean Construction practice. Chapter six established that to manage the challenges of Lean Construction techniques, there is a need to: promote awareness on benefit of the application of Lean Construction techniques on construction sites; simplify the language of Lean Construction; instil confidence in site team and supply chain on the workability of lean techniques; train workers on lean techniques; get clients to insist on Lean application, get legislative support; publication of results; reduce the fear/ reservations in workers' mind; get top management involvement and support; persistence, robust planning; workers involvement and empowerment; create awareness programs; government policies; and implement the Lean concepts at a gradual level.

7.1.5 Output

It is, expected that upon implementation of the outlined solutions above, the full safety benefits of Lean Construction techniques would be realised. Though the key driver for adopting this framework is to improve safety, other indirect benefits attached to improvement in safety improvement are less project cost and duration, employee satisfaction, higher productivity, resources efficiency, less injuries and accidents, enhanced company and industrial reputation.

7.2 The Framework

Given the preceding discussions, the link between Lean Construction and safety on construction can be conceptualised as an integrated framework depicted by Figure 7.1. The figure demonstrates that to promote safety, being one of the drivers of Lean practice, certain inputs are required. An input is something an organisation put into its system to achieve some targeted results. It is what is required of the organisation to do in order to improve safety. In this case, the input is to engage in the wholistic application of Lean Construction principles in its entire system. By engaging in Lean Construction practice, the organisation does not just directly apply the tools. It has to first ensure that both the employers and employees understand and apply the Lean principles. Both should also adopt a continuous improvement culture as a philosophy across all activities in the organisation.

The processes involve the selection and application of the appropriate Lean Construction tool or techniques to achieve the desired outcome. In this case, the processes involve applying the appropriate techniques (L1-L22) identified in the matrix (table 7.1) to address the relevant safety issue (S1-S20) as shown in the matrix. These techniques are applied at the construction phase of the project to reduce onsite accidents from occurring. They could also be used to reduce workers exposure to risks and hazards that develop on construction sites at the construction stage. Subsequently, the challenges that confront application of the lean techniques on construction sites must be addressed. The logic of the framework, therefore, is that upon identification of the appropriate Lean Construction tools and techniques as inputs, and application of the right process mix, while at the same time addressing their challenges, improved safety standards will be achieved on construction sites. This in effect will lead to good safety records, improve construction organisations image and reputation, prevent waste of time and resources both human and material, and eventually make construction organisations more competitive.

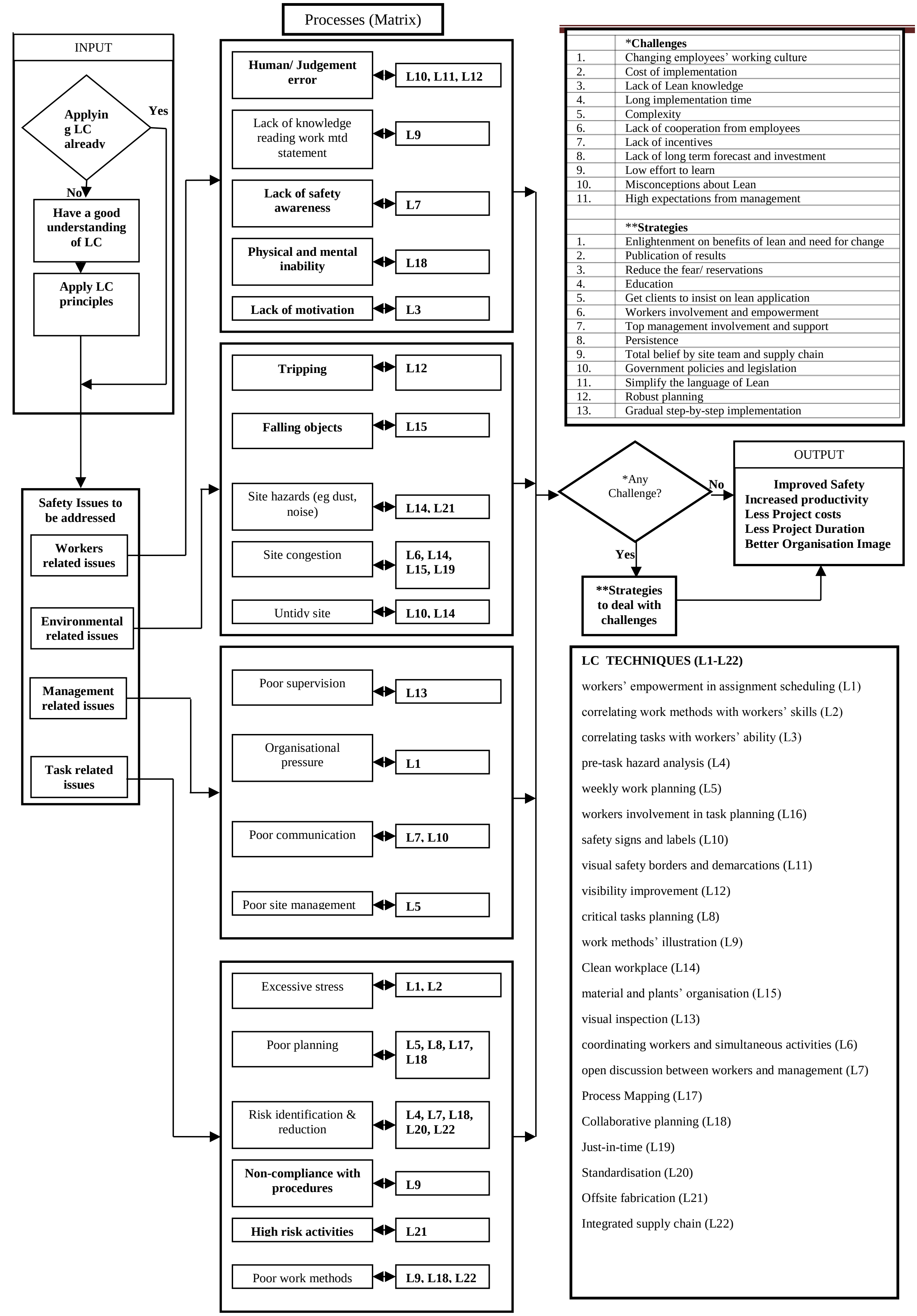


Figure 7. 1 Framework for utilising Lean Construction Techniques to Promote Safety on Construction Sites

7.3 Summary

This chapter presented the outcome of the research. It initially summarised the research noting the major findings. The chapter then, on the basis of the qualitative and quantitative study findings, presented an integrated framework that could serve as a guide to contracting organisations in using Lean Construction techniques to achieve an improvement in safety on construction sites. Having developed such an integrated framework, the research moves to validate the framework from practitioners' viewpoint. The next chapter presents the validation process.

CHAPTER 8: RESEARCH VALIDATION

8.0 Introduction

The previous chapter presented the outcome of the research findings in the form of an integrated framework to guide contracting organisations in using Lean Construction techniques to promote safety by reducing chances for accidents to occur. However, the extent to which the research findings can be relied upon depends on the validation processes conducted in establishing its validity. In order to address the fifth objective of the research, this chapter presents the validation process undertaken.

8.1 Research Validation

The purpose of research findings is to provide measures that can be applied to improve existing processes or procedures. Hence, it is important to establish the validity of such findings so that expected process improvement can be reliably achieved when the findings are put into practice. According to Hair *et al*., (2010), validation is the process of assessing the degree to which a measure accurately represent what it purports or is required to measure. However, validation process is carried out not only to establish the validity of research findings but also the validity of the research design (Brewer, 2000). In line with this, there are four aspects of validity that need to be established in a validation process (Cook and Campbell, 1979; Shadish *et al*., 2002). These are:

1. Validity of research constructs
2. Validity of statistical findings
3. External validity
4. Internal validity

The validity of research constructs and statistical findings has been established through pilot studies and inferential statistical techniques such as chi-square and spearman’s correlation test as discussed in Chapter 6. Hence, the focus of validation presented in this chapter is on external and internal validation.

8.1.1 External Validation

This is the process of establishing the extent of generalisability of research findings in spite of variations in the settings, persons and research method adopted (Shadish *et al.*, 2002; Fellows and Liu, 2008). According to Brinberg and McGrath (1985), external validation process is meant to gain confidence in research findings and it is a process that transforms findings to knowledge. External validation comes in three aspects: replication, boundary search and convergence analysis.

8.1.1.1 Replication

Replication is the process of repeating a research process in order to establish whether the exact set of findings can be produced again (Rosenthal and Rosnow 1991). Kerlinger and Lee (2000) see it as a reliability test for the research. However, given the logistical constraints of repeating the processes involved in a social research, replication is practically not possible and rarely used (Brinberg and McGrath 1985; Ankrah 2007). Also, due to financial constraint of conducting a PhD research, replication approach was not adopted in this research but the questionnaire survey was adequately designed and pre-tested with a pilot study to ensure reliability of the research findings.

8.1.1.2 Boundary Search

Boundary search is the process of establishing the conditions under which the findings of a research will not hold (Brinberg and McGrath 1985). Boundary search is carried out over time through replication and convergence analysis. Though this external validation process was not executed in this research due to the time and cost constraints, the convergence analysis approach was adopted.

8.1.1.3 Convergence Analysis

Convergence analysis involves the use of different research methodologies or strategies to ascertain the agreement of research findings (Ankrah 2007; Denzin 2009). In this research, the use of qualitative and quantitative methods revealed significant agreement between the research findings from the two methods. Hence, this convergence has been thoroughly demonstrated in sections 6.5.1, 6.5.2, 6.5.3, 6.5.4 and 6.5.5.

Silverman (2006) noted that convergence validation could also be achieved through a process called respondent validation, which involves the use of research participants' opinions to verify the validity of research findings (Silverman 2006; Creswell 2009). This approach to convergence analysis has been considered as a characteristic of a good research (Reason and Rowan 1981) and thus, adopted in previous construction management research (Hari *et al*., 2005; Ankrah 2007; Anvuur, 2008; Tuuli 2009; Manu 2012). In this case, a follow up interview with the respondents could be used to validate research findings (Phua 2004). This approach was adopted in this research using Lean Construction practitioners. The structured interview contains questions that intend to verify the validity of the research findings and the relevance of the framework developed to the construction industry and more specifically contracting organisations (see appendix G). The framework was presented in the form of a flowchart showing the process map in a way that industry professionals are more familiar with (see figure 7.1).

The participants selected for the convergence validation were among the respondents that participated in the qualitative study and quantitative survey, who indicated their interest in the findings of the research and in participating in subsequent stages of the research. A total of 29 Lean practitioners were invited to participate in the validation process. The interview questions and framework were sent along with the invitation, followed by phone interviews with those who agreed to participate.

8.1.1.3.1 Results of Respondent Validation

Telephone interviews were conducted with 5 Lean practitioners across five Lean practicing contracting organisations. These include an Operations manager (V1), a Lean technical officer (V2), a Health and safety manager (V3), a Construction director (V4) and a Director of special projects (V5). The average years of working experience of the respondents is 30 years while their average years of practicing Lean Construction is 5 years. The senior management levels and years of experience of the respondents demonstrate that they are in a good position to give knowledge-based opinions for the validation of the findings of this research.

The feedback on the validity of the findings of this research, as shown in Table 8.1, indicated that the findings are valid. Regarding the statement that "the developed framework could be used to address workers-related safety issues", 3 of the respondents indicated that the finding is valid while 2 indicated that it is highly valid. To further consolidate their views and suggest how the framework could be improved, V4 and V5 made the following statements:

"Yes, valid – it can encourage workers to engage in the project". [V4]

"Yes, valid - it is easier to read using a matrix. The techniques are not new to what we do, but it shows us how we could use it to achieve particular health and safety benefits". [V5]

Since an interaction matrix has already been designed (see Table 5.13), it will be attached to the framework to facilitate its application as suggested by V5.

In response to the statement that "the Lean techniques labeled L6 to L21 in the framework could be used to address environment-related safety issues as identified in the framework, the responses were affirmative that this finding is valid. 4 indicated valid and 1 indicated highly valid. Similarly, the following remark was made by V4 to support the validity of the finding:

"Yes, valid - human attitudes can further help in addressing these issues" [V1]

Based on suggestion made by V1, it is recommended that future research looks at how human attitudes could be used to address environment-related safety issues.

In response to the statement that "the Lean techniques labeled L5 to L13 in the framework could be used to address management related safety issues", 4 of the respondents indicated that it is valid while 1 respondent (V2) indicated that it is not valid. The reason according to the respondent is that organisational pressure may not be addressed through workers' empowerment alone, rather it should be addressed through "*involvement of workers, specialist subcontractors and the management in planning the site and tasks to be carried out."*

Therefore, it is also recommended that future research should look at how organisational pressure could be addressed through the involvement of workers, specialist subcontractors and the management in planning the site as well as site operations.

The following remark was made by V4 to support the validity of the finding and suggest ways of improving it:

“Yes, valid – but it will only be of use if knowledge is used to prevent it happening again” [V4]

Since the early stage of the framework emphasizes on a good knowledge and understanding of Lean construction, it is expected that this knowledge will be used in preventing accidents as suggested by V4.

Similar to the assessment on the impact of Lean Construction techniques on safety issues described above, the respondents responded in the affirmative that “the Lean techniques labeled L1 to L22 in the framework could be used to address task-related safety issues”, with 4 respondents indicating that finding is valid while 1 indicated that it is highly valid. In support of their responses, some of the respondents made the following remarks:

“Yes, valid – they are common issues that we all face” [V1]

“Yes, valid – but when time becomes a constraint, workers will want to go back to poor work practices” [V4].

Therefore, it is recommended that organisations should efficiently manage time allocated for the project so that workers will not be subjected to time pressure. In situations where time becomes a constraint, proper measures should be taken to prevent workers from going back to poor work practices.

In order to demonstrate the applicability of Lean in addressing safety in construction, respondents were asked to indicate their level of agreement with the finding of this research that “Lean Construction techniques could be used to promote safety on construction sites using the developed framework”. The responses were emphatic with 4 respondents agreeing and 1 strongly agreeing (see Table 8.1).

Table 8. 1 Feedback on Validity of Findings

	Responses				
	No response	Not sure	Not Valid	Valid	Highly Valid
1. the Lean techniques labeled L3,…, L10 on the framework could be used to address workers related safety issues	0	0	0	3	2
2. the Lean techniques labeled L12,…, L14 on the framework could be used to address environment related safety issues	0	0	0	4	1
3. the Lean techniques labeled L5,…, L13 could be used to address management related safety issues	0	0	1	4	0
4. the Lean techniques labeled L1,…, L22 could be used to address task related safety issues	0	0	0	4	1

To buttress their point, some of the respondents made the following remarks to support the validity of the findings:

"the framework has reinforced my perception and observations" on the safety benefits of Lean practice. [V4]

"The techniques are not new to what we do, but it shows us how we could use it to achieve particular health and safety benefits" [V5]

The respondents also made the following comments to suggest ways of improving the framework:

"Colours should be introduced into the flowchart to make it easier to follow". [V3]

"Workers commitment is necessary to achieve a successful application of the framework". [V4]

"Workers have to be fully engaged (involved) in applying the framework". [V1]

"Using a framework may be useful but the organisation using it would need to clearly understand the effect of the lean techniques and have experience of them in order to make the choice…. Attaching data on accidents on sites where Lean techniques are used versus sites where it is not will help if the results show reduction in accidents occurrence". [V2]

"If it is possible don't call it Lean rather let's call it "using business improvement techniques" to promote health and safety so that it doesn't sound too new". [V5]

The suggestions made by V1, V2, V4 and V5 above are among the strategies identified in overcoming the challenges to applying Lean Construction techniques in the organisations (see Section 5.9).

Though V3 suggested the introduction of colours into the framework, the framework was not changed. However, the use of colours is recommended in the development of web-based version of the framework.

Table 8. 2 Feedback on the Potential benefit of developed Framework

	Responses					
	No response	Strongly disagree	Disagree	Neutral	Agree	Strongly agree
Lean Construction techniques could be used to promote safety on construction sites using the framework	0	0	0	0	4	1

While it is important to verify the validity of the findings of this research, it is equally important to evaluate the relevance of the framework developed in this research to the construction industry. In order to achieve this objective, respondents were asked to assess the industrial relevance of the framework. Table 8.3 shows that 3 of the respondents indicated that the framework is relevant while 2 indicated that the framework is very relevant to their practice. Also, the following suggestions were made by one of the respondent to buttress his views on the industrial relevance of the framework:

"The framework has shown another benefit of Lean more clearly, what strategies in light of the benefits of Lean. It is of much relevance to us". [V5]

In order to assess how comprehensive are the challenges facing application of Lean Construction techniques in contracting organisations identified in the study, respondents were asked to indicate if the list of challenges presented to them has exhausted all the existing challenges. Table 8.4 shows that 2 respondents indicated ***Yes*** while 3 of them indicated ***No***.

Table 8. 3 Feedback on the relevance of the developed Framework

	Responses			
	No response	Not relevant	Relevant	Very relevant
How relevant did you find this framework?	0	0	3	2

Some of the respondents suggested the following as additional challenges to complement the list:

"Contractors are more obsessed with cash flow rather than waste removal; contractual terms and conditions give disincentive; and lack of client pull across the sector". [V2]

"The fragmented nature of the supply chain is a challenge facing Lean Construction". [V3]

"*Getting clients to accept the idea is another challenge"*. [V4]

Though some of the challenges identified by V2, V3 and V4 are already incorporated in the framework (see Section 5.8, p103), it is recommended that future research should look at the additional ones.

The respondents were asked to assess how comprehensive is the list of strategies that could be used to overcome the challenges facing Lean Construction practice. Table 8.4 shows that 3 respondents responded with ***Yes***, indicating that the list of strategies is comprehensive (***Yes***) while 2 responded with *No* and as such suggested the following to compliment the list:

"Creating contractual requirements for Lean practice and making Lean part of the site Health and safety induction." [V2]

"Lean knowledge and enlightenment on its benefit should have the priority. Workers' involvement is the top priority, clients also need to be enlightened besides workers in the organisations. The site team must also be committed to it." [V5]

"Senior Managers in the supply chain and clients need to lead by example". [V1]

Though some of the strategic solutions suggested by V1 and V5 are already incorporated in the framework (see Section 5.9, p111), future research should also look at the additional strategies identified.

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Table 8. 4 Feedback on challenges and strategies to overcome challenges facing Lean Construction practice

	Responses		
	No response	Yes	No
1. Does the framework exhaust all the challenges	0	2	3
2. Does the framework exhaust all the strategies	0	3	2

8.1.2 Internal Validation

An internal validation was carried out to ensure that the research findings are free of bias (Garson 2011). Fellows and Liu (2008) and Garson (2011) suggest that an internal validity could be achieved through a good research design. Internal validation could also be achieved through agreement of findings with published research and also through academic validation achieved via research publications. Some researchers have further demonstrated internal validation by establishing convergence between research findings, published research and academic validation. Such previous studies include Proverbs (1998), Xiao (2002) and Ankrah (2007). According to Manu (2012), this approach has been used in construction management doctoral studies in order to assess the studies against published works and subject the studies to expert scrutiny. Therefore, this section presents how this research demonstrates internal validity.

Agreement of research findings with published work is described by Black (1993) and De Vaus (2002) as a criterion for validity. This refers to how related a new measure of a concept is to the existing measure of the concept. The agreement of the findings of this research and published research has been demonstrated in chapters 5 and 6.

Academic validation involves the dissemination of the findings of this research through seminar presentations, doctoral workshops, conferences and journal papers which are subject to peer review. A peer review of the research publications provided an opportunity for the methodologies, meanings and interpretations of research to be questioned by independent judges (Xiao 2002). Academic forums such as seminars, workshops and conferences were also used to scrutinise the research findings and receive feedback and comments which were also incorporated in the research to improve its validity. So far, in this research, the following papers have been published and presented in doctoral workshops and conferences:

Journal Papers:

1. Bashir A. M., Suresh S., Oloke, D. A., Proverbs, D. G. and Gameson R. (2013) “Effect of Lean Construction Tools on Accident Prevention in Uk Contracting Organisations”. *Journal of International Real Estates and Construction Studies*.

2. Bashir A. M., Suresh S., Oloke, D. A., Proverbs, D. G. and Gameson R. (2013) “Overcoming the Challenges facing Lean Construction Practice in the UK Contracting Organisations”. *Lean Construction Journal*. (**under review**)

Conference and Doctoral Workshop Papers

1. Bashir A. M., Suresh S., Oloke, D. A., Proverbs, D. G. and Gameson R. (2013) “Application of Lean Construction Tools in the UK Contracting Companies- Findings from Qualitative Studies”. Proceeding for Architectural Technology Institute Conference, Pennsylvania University, April 2013.

2. Bashir A. M., Suresh S., Proverbs, D. G. and Gameson R. (2011) “A Critical, Theoretical, Review of the Impacts Of Lean Construction Tools in Reducing Accidents on Construction Sites”. *In:* Egbu, C. and Lou, E. C. W. (eds.) Proceedings of the Association of Researchers in Construction Management (ARCOM) conference at University of the West of England (UWE) Bristol in September 2011.

3. Bashir A. M., Suresh S., Proverbs D. G. and Gameson R. (2011) “How the Concepts of Increased Visualisation, Daily Huddle Meetings and Error-proofing can reduce the likelihood of Accidents”. Handbook of the 54th Operational Research Society (ORS) Conference at Nottingham University, Nottingham in July 2011.

4. Bashir A. M., Suresh S., Proverbs D. G. and Gameson R. (2011) “A Critical Review on Lean Construction Tools and their Role towards Health and Safety on Construction Sites”. Proceedings of the Lean Construction Institute (LCI-UK)/ Association of Researchers in Construction Management (ARCOM) Doctoral Workshop, Northumbria, United Kingdom 2011.

5. Bashir A. M., Suresh S., Proverbs D. G. and Gameson R. (2010) “Barriers Towards the Sustainable Implementation of Lean Construction in the United Kingdom Construction Organisations”. Proceedings of the Association of Researchers in Construction Management (ARCOM) Doctoral Workshop, Wolverhampton, United Kingdom 2010.

Seminars and Presentations

1. A presentation titled “The Development of a Framework for Promoting Safety on Construction Sites using Lean Strategies” was made at PhD students workshop organised by the Lean Construction Institute (LCI-UK) at Nottingham Trent University, Nottingham in April, 2012.

2. A seminar titled “Safety benefits of Lean Construction practice” was also presented at the June 2012 Built Environment and Engineering Research Seminars (BEERS) at School of Technology, University of Wolverhampton in respect to findings from the Qualitative study.

3. A presentation titled “Lean Strategies for Promoting Safety on Construction Sites: A Conceptual Framework” was made at a Lean Construction workshop organised by the Lean Construction Institute (LCI-UK) at Salford in October, 2010.

4. A seminar titled “Exploring Lean Construction as a Strategy for promoting Safety in the UK Construction Industry” was also presented at the May 2010 Built Environment and Engineering Research Seminars at School of Engineering and the Built Environment, University of Wolverhampton, in respect to findings and development from the literature review.

8.2 Summary

The chapter has presented the processes undertaken to validate the study findings both externally and internally. The external validation was carried out using the convergence analysis approach through respondents’ validation. A telephone interview was conducted with 5 lean practitioners to validate the research findings as well as evaluate the relevance of the framework in the construction industry. Generally, the respondents concur to the research findings and believe that the framework could be used to address the safety issues identified. However, they noted additional techniques that could be added to the framework and also suggested ways of improving the framework. Furthermore, the respondents are of the opinion that the framework is relevant to the construction industry in promoting safety. while the respondents considered the list of challenges and strategies for addressing the challenges to be comprehensive, they suggested additional challenges and strategies.

Though most of the suggestions made by the respondents across different stages of the validation interview are already captured in the framework, future research should also look at the additional strategies identified.

On the other hand, the internal validation was established through agreement between past studies and the research findings and also through academic validation of the research publications.

Having validated the research findings, the fifth research objective has now been fully addressed. The next chapter draws conclusion on the entire research and makes recommendations.

CHAPTER 9: CONCLUSIONS AND RECOMMENDATIONS

9.0 Introduction

The sixth objective of the research is to draw conclusions on the relevance of Lean Construction techniques in promoting safety on UK construction sites, and make recommendations to practitioners and for future research. To achieve this objective, the chapter begins with summary of the research findings, across the objectives, on the basis of which conclusions are drawn. Following the conclusions, the chapter makes recommendations to practitioners, policy makers and future researchers.

9.1 Summary of the Research Findings

Chapter one sets out the background of the research. The chapter noted that the UK construction industry is plagued with accidents on construction sites. It is suggested that Lean Construction principles and techniques could be used to ameliorate this poor safety situation. However, to date, Lean Construction principles have not received adequate application within the UK construction industry. A major reason to this could be lack of exploration of the relationship between Lean Construction principles and safety practices on the UK construction sites. This is further compounded by several arguments within the relevant literature that Lean Construction could rather expose workers to poor safety conditions. This study therefore sought to investigate based on empirical evidence the relationship between the Lean Construction techniques and safety on construction sites. In order to address this aim, a number of objectives were identified. The discussion below summarises how the objectives were achieved.

9.1.1 Health and Safety Performance of the UK Construction Industry

To satisfy the first objective, Chapter 2 reviewed the relevant literature on causes of accidents on the UK construction sites with a view to assess the potential influence of Lean Construction techniques in helping to mitigate them. The chapter found two main causes of accidents on construction sites namely: onsite and offsite causes (see Section 2.6). It was noted that Lean Construction techniques are suitable for redressing a number of onsite causes of construction accidents.

9.1.2 Lean Construction and its Impact on Safety

To satisfy the second research objective, Chapter 3 reviewed the relevant literature on Lean thinking and its relationship with safety practices in the construction industry. The chapter noted 3 major categories of studies on the relationships between Lean Construction techniques and safety practices on construction sites. The first category argued that the application of Lean principles on construction sites could expose workers to poor safety conditions. However, apart from these studies not based on empirical evidence, they do not clarify how Lean Construction practice could impact negatively on safety. Therefore, empirical evidence is required for this group's claim to be valid.

Conversely, the second group claims that Lean Construction techniques could improve safety without stating how they do so. Finally, the third category of studies identifies 11 ways by which Lean Construction techniques could be used to promote safety on construction sites. However, these ways had received little empirical examination. In addition, it was established that these relationships could be prone to several challenges and thus, also required further investigation based on empirical evidence.

The chapter further identified 12 potential relationships between the onsite causes and certain lean techniques based on a logical analysis. The chapter constructed a matrix of how the Lean Construction techniques could be used to promote safety on construction sites based on the 23 relationships identified as the outcome of the literature review. On the basis of the matrix, the chapter developed a conceptual framework to show how Lean Construction practice could be used to promote safety in the UK construction industry, taking into account the required input, the challenges and the strategies that could be used to address them. However, the relationships identified in the framework were not based on adequate empirical evidence. Therefore, there was a need to engage Lean practitioners to test the validity of these relationships and also to explore other ways Lean Construction techniques could be used to promote safety. In doing so, there was also a need to adopt the most appropriate methodology in conducting the exploratory study.

9.1.3 Methodology for Investigating Safety Relevance of Lean Construction Techniques

Chapter 4 presented how the research was designed, and data was obtained and analysed to address the research question, aims and objectives. To identify the most appropriate methodology, Chapter five made an extensive review of the various methodology options and identified the most suitable approach in collecting the requisite data, analysing the results and testing the validity of the findings. This was done putting the research limitations and constraints into consideration. The qualitative study was found to be the most suitable approach in exploring the relationship to further develop the conceptual framework while the quantitative study was selected as a strategy for testing the different components of the conceptual framework using a large sample of Lean practitioners.

9.1.4 Developing the Conceptual Framework for Utilising Lean Construction Techniques to promote Safety

To satisfy the third objective, Chapter 5 presented findings from the qualitative study conducted with 10 contracting organisations practicing Lean Construction within the UK construction industry. Though the organisations apply the same Lean Construction principles, they tend to apply few tools of varying type. A total of 21 Lean Construction tools and 18 drivers were found to be applied in the organisations. Some of the tools have similar benefits but they are applied in different ways and called with different names. Due to variations in the drivers for adopting Lean Construction, the tools selected were found to differ between the organisations. Furthermore, only tools considered appropriate in addressing such drivers were applied. Hence, the study concludes that the drivers to Lean Construction practice in an organisation play a role in determining what tools are selected and applied in the organisation.

In addition to the 23 relationships identified from the literature review, the qualitative study further discovered 15 new relationships between Lean Construction techniques and safety. Six out of the 23 relationships (identified in the literature review) were confirmed from interactions with the industrial experts. A total of 38 relationships were, thus, established by the study. All the 21 relationships found from the qualitative study exhibit a positive relationship. Hence, the study found that lean techniques have no negative impact on safety across all the 10 organisations. This was reflected on the conceptual framework.

The chapter also found that Lean Construction practice is faced with 11 different challenges in these organisations. Six of them were already known in the literature, while additional five challenges were discovered. The 5 new challenges are high expectations from the management, low efforts to learn, lack of long term forecast and investment, non-compliance with instructions, and lack of incentives. Similarly, the study identified 13 different strategies that could be used to address these challenges. However, all the strategies are not specifically focussed on addressing particular challenges. Therefore, further research is needed to clarify which strategy could be used in addressing a particular challenge.

9.1.5 Assessing the Conceptual Framework

To satisfy the fourth research objective, Chapter 6 presented findings from the quantitative study used to test the different components of the framework. The findings established that all the relationships related to workers-related Lean techniques, planning-related Lean techniques, task-related Lean techniques and communication-related Lean techniques have Rwg values ≥ 0.76 indicating that they could reduce accident causations. Similarly, all the statements on visual management techniques had Rwg values ≥ 0.76 with the exception of the statement (relationship) “Safety signs and labels could reduce accidents caused by untidy site”. Furthermore, with the exception of the relationship “Just-in-time could reduce accidents caused by site congestion”, all the statements on Lean techniques categorised as “Other Lean techniques”, were found to have Rwg values ≥ 0.76, indicating that they could reduce accident causations. Though the quantitative study validated 36 out of the 38 identified relationships between Lean Construction techniques and safety issues, the remaining 2 relationships were also identified from interactions with Lean practitioners (see Section 5.5, p100).

The chapter found that improving productivity, safety, and efficiency are the most important factors that influence the organisations to engage in Lean Construction practice while the least are the government reports related to Lean Construction practice. The factors identified as drivers to Lean Construction practice in the qualitative study were tested and validated.

The chapter also found that lack of Lean Construction knowledge, misconception about Lean and its complexity are the biggest challenges facing Lean Construction practice in the organisations while the least is unsuitable organisational structure to support Lean Construction practice. The challenges facing Lean Construction practice were also tested and validated.

9.1.6 Integrated Framework

To satisfy the fifth research objective, Chapter 7 presented the outcome of the study; an integrated framework developed based on findings from the literature review, qualitative study and quantitative study to guide contracting organisations in using Lean Construction to promote safety. The framework consists of 3 parts; input, processes and output. The input is what the organisations put into the system, the processes are the interactions that occur to generate the desired output. In this case, the input is the application of Lean Construction principles and tools, the process is the selection and adoption of appropriate lean techniques to address certain safety issue, and the output is the promotion or improvement in safety practice, less waste of resources (human, financial and time) and better reputatation. The integrated framework also suggested the strategies that could be adopted in addressing any challenge to or arising from the processes. The adoption of this integrated framework was identified as a strategy for using Lean Construction techniques to promote safety on the UK construction sites.

9.1.7 Research Validation

To fully satisfy the fifth research objective, Chapter 8 presented findings from the validation process. The entire research findings were validated using an external and internal validation processes. In the external validation, respondent validation was used to carry out a convergence analysis. A telephone interview was conducted with 5 lean practitioners to validate the research findings as well as evaluate the relevance of the framework in the construction industry. Generally, the respondents concur to the research findings and believe that the framework could be used to address the safety issues identified. However, they suggested ways of improving the framework. Furthermore, the respondents are of the opinion that the framework is relevant to the construction industry in promoting safety. Though the respondents considered the list of challenges and strategies for addressing the challenges to be comprehensive, they suggested two additional challenges and strategies.

On the other hand, the internal validation was established through agreement between past studies and the research findings and also through academic validation of the research publications (see Section 8.1.2).

9.2 Overall Conclusion

The UK construction sector has over the last decade recorded the highest occupational related death rates due to poor safety. Advocates of Lean Construction suggest that Lean Construction practice promotes safety. On the other hand, a number of studies argued that Lean Construction practice would rather expose workers to poor safety. However, both sides lack adequate empirical evidence to support their arguments.

In this research, the different ways in which Lean Construction practice impact on safety were identified based on an extensive critical literature and empirical evidences obtained from 10 contracting organisations using a qualitative exploratory study. A total of 38 different relationships were identified. However, all the relationships are directed towards positive impact on safety. Based on these relationships, the challenges facing Lean Construction practice and the strategies to address them, an interaction Matrix and a conceptual framework were developed to conceptualise how Lean Construction techniques could be used to promote safety on the UK construction sites. A survey was conducted, with 92 lean practitioners working in 53 lean production organisations, to test and validate the different components of the conceptual framework. These include the Processes or relationships identified, the drivers/ purpose for applying lean techniques, the Challenges facing lean practice and the Outcomes of Lean Construction practice in the organisations. A total of 36 relationships were established at the end of the validation process.

The study found that improving productivity, safety, and efficiency are the most important factors that influenced the organisations to engage in Lean Construction practice while the least are the government reports related to Lean Construction practice. Similarly, the biggest challenges facing Lean Construction practice are lack of Lean Construction knowledge, misconception about Lean and its complexity while the least is unsuitable organisational structure to support Lean Construction practice. This shows that the UK construction industry still lacks adequate knowledge on Lean Construction. In fact even the companies applying

Lean Construction are still in need of enlightenment and training on Lean Construction principles and tools.

The findings were used to advance to an integrated framework to guide contracting organisations in using Lean Construction practice as a strategy for promoting safety practice on construction sites. Lean Construction practice can therefore be adopted by construction organisations as a way of promoting safety. Furthermore, Lean Construction practice can be incorporated into the government health and safety initiatives for improving safety performance of the UK construction industry.

9.4 Recommendations for Further Research

The following are the recommendations in respect to future research.

- There should be further research on the 2 relationships found from the qualitative study but not agreed upon by participants in the quantitative study (refer to Sections 6.5.2.6 and 6.5.2.7).
- A deeper research on each of the challenges to provide a wider range of strategies that could be used to address it.
- A deeper research on each strategy to see how it could be implemented or applied to overcome a particular challenge or range of challenges.
- An experimental research on each of the Lean techniques to study practically its impact on safety as an alternative to practitioners' views used in this study.
- Based on the outcome of this research, further research should look at the development of a web-based tool that will enable users to access the different antecedents of Lean Construction and safety issues to interactively make informed decisions in promoting safety. Colours should be incorporated into the tool to facilitate communication.
- In order to enhance and broaden the knowledge of health and safety among students and practitioners, the relevance of Lean construction strategies in promoting safety should be incorporated into the educational (undergraduate, post graduate and continuing) and training (CPD) curricula.

9.5 Recommendations to Policy and Practice

The following are the recommendations in respect to practitioners (construction industry) and the government.

- Lean Construction practice should be incorporated into government health and safety initiatives, regulations and policies to promote safety practice.
- Lean practicing organisations should adopt the identified strategies as a way of overcoming the challenges facing Lean Construction practice in their organisations to achieve the desired drivers for implementing Lean Construction in the organisation.
- Lean Construction is mainly applied in organisations for the purpose of addressing certain drivers, such as cost and time. As such, an organisation mainly focusses on measuring improvement in respect to those drivers, while the impact of Lean Construction practice in other areas goes unnoticed. The impacts of Lean Construction should be explored from different perspectives, beyond the primary purpose of its application, so as to maximise the identification of its additional impacts.
- Contracting organisations that wish to apply this framework should engage its staff in a Lean Construction seminar, workshop or a training session to acquire all the necessary knowledge and skills required to achieve its smooth implementation. The training should also be an avenue where adequate guide will be given to the workers in implementing the framework.
- A good knowledge of the safety benefits of Lean construction techniques and the ability to adopt them in promoting safety should be considered as an essential requirement when recruiting health and safety managers, site managers and project managers in construction organisations.

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APPENDICES

APPENDIX A: DETAILS OF PUBLICATIONS

Book Chapter

*1. Suresh, S., Bashir A., M. and Olomolaiye, P. O. (2012) "A Protocol of Lean Construction in Developing Countries". In *"Contemporary Issues in Construction in Developing Countries"* edited by Professor George Ofori of National University Singapore and published by SPON press, New York.

Journal, Conference and Doctoral Workshop Papers

1. Bashir A. M., Suresh S., Proverbs D. G. and Gameson R. (2010) Barriers towards the Sustainable Implementation of Lean Construction in the United Kingdom Construction Organisations. Proceedings of the Association of Researchers in Construction Management (ARCOM) Doctoral Workshop, Wolverhampton, United Kingdom 2010.

2. Bashir A. M., Suresh S., Proverbs D. G. and Gameson R. (2011) A Critical Review on Lean Construction Tools and their Role towards Health and Safety on Construction Sites. Proceedings of the Lean Construction Institute (LCI-UK)/ Association of Researchers in Construction Management (ARCOM) Doctoral Workshop, Northumbria, United Kingdom 2011.

3. Bashir A. M., Suresh S., Proverbs, D. G. and Gameson R. (2011) A Critical, Theoretical, Review of the Impacts Of Lean Construction Tools in Reducing Accidents on Construction Sites. *In:* Egbu, C. and Lou, E. C. W. (eds.) Proceedings of the Association of Researchers in Construction Management (ARCOM) conference at University of the West of England (UWE) Bristol in September 2011.

4. Bashir A. M., Suresh S., Proverbs D. G. and Gameson R. (2011) How the concepts of Increased Visualisation, Daily Huddle Meetings and Error-proofing can reduce the likelihood of Accidents. Handbook of the 54th Operational Research Society (ORS) Conference at Nottingham University, Nottingham in July 2011.

*This publication is not directly related to this research, but it was published during the study period as a result of skills acquired over the period.

5. Bashir A. M., Suresh S., Proverbs, D. G. and Gameson R. (2013) “Application of Lean Construction Tools in the UK Contracting Companies- Findings from Qualitative Studies”. Proceeding for Architectural Technology Institute Conference, Pennsylvania University, April 2013.

6. Bashir A. M., Suresh S., Oloke, D. A., Proverbs, D. G. and Gameson R. (2013) “Overcoming the Challenges facing Lean Construction Practice in the UK Contracting Organisations”. To be submitted for publication in Lean Construction Journal 2013.

7. Bashir A. M., Suresh S., Oloke, D. A., Proverbs, D. G. and Gameson R. (2013) “Effect of Lean Construction Tools on Accident Prevention in Uk Contracting Organisations”. *Journal of International Real Estates and Construction Studies 2013.*

APPENDIX B: ETHICAL APPROVAL LETTER

Dear Bashir

This is to confirm that the Ethics Committee has approved your ethical proposal.

Best wishes

Patricia

Patricia Osborne
International Administrator
School of Technology
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APPENDIX C: INVITATION TO PARTICIPATE IN THE INTERVIEW

Dear Sir,

I am a research student at the University of Wolverhampton undertaking a Ph.D. research entitled: "Lean strategies for promoting Safety on Construction Sites". The doctoral research is partially sponsored by the University of Wolverhampton. I would like to invite you to participate in an interview, as part of the research, which aims to investigate the potential impact of Lean Construction concepts on safety. Your company has been selected due to your participation in the Construction Lean Improvement Programme (CLIP).

A copy of the interview is attached. The purpose of the interview is to obtain your opinion on the safety impacts of Lean Construction concepts. The interview is estimated to last for about 45 minutes. Data obtained from the interview will be treated with strict confidence and used for academic purposes only. No records will bear your company's name. The interview will be held preferably between now and the end of August.

If you have any questions or queries, please do not hesitate to contact me. Thank you very much in advance for your time and valuable assistance in this research.

Yours sincerely,

Abubakar M. Bashir

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APPENDIX D: INTERVIEW SCHEDULE

THE INTERVIEW

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DOCTORAL RESEARCH INTO IMPACTS OF LEAN CONSTRUCTION ON SAFETY

INTRODUCTION

The author of this interview is currently a doctoral student at the University of Wolverhampton. This interview is part of a doctoral research which aims to investigate the impact of Lean Construction tools on safety on UK construction sites. The interview is in four sections:

Section A requests information on the respondents and their organisation's profile.

Section B focuses on the current application of Lean Construction concepts in construction organisations and examines levels of awareness, knowledge of and drivers for applying Lean concepts on construction sites.

Section C focuses on the impacts of the features of Lean Construction tools on safety.

Section D focuses on the benefits organisations expect from applying Lean Construction, the barriers and challenges facing Lean Construction practice and how these could be addressed.

Your contribution in answering these questions would be most appreciated. All measures are in place to ensure that the answers are treated with strict confidence and used for academic purposes only.

Interview Schedule

Section A- *Introduction*

1. What is your current designation within your organisation?
2. How long you have worked in the construction industry?
3. What is the type and size of the projects your organisation mostly engages in?
4. What is the geographic area in which you operate?
5. How is your role related to ensuring safety on projects?

Section B- *Drivers of Lean Construction Practice*

6. Describe your understanding of the term "Lean Construction"
7. Please describe to what extent your company has applied Lean Construction?
8. What aspects of Lean do you apply in your organisation?
9. What are the drivers behind your organisation's decision to apply Lean Construction?
10. What in your understanding prevents many organisations from applying it?

Section C- *Impact of Lean Construction on Safety*

11. From your experience, describe the impact of Lean Construction concepts on safety?
12. Please give an illustration or example of how Lean concept(s) can impact on safety?

Section D- *Benefits and Challenges of Lean Construction Practice*

13. What positive impacts has Lean Construction practice made in your organisation?
14. What negative impacts has it made in your organisation?
15. In what various ways have you realised the benefits of its application?
16. What challenges do you encounter in its application?
17. How do you think these challenges can be addressed?
18. Do you wish to make any other comments in regard to the impact of Lean Construction techniques on safety?
19. Do you wish to receive a summary of the research findings?
20. Would you be willing to be involved in a subsequent phase of the research?

END OF THE INTERVIEW- THANK YOU FOR YOUR TIME!

APPENDIX E: PILOT SURVEY QUESTIONNAIRE

Section A:- Profile of Respondent/ Organisation

1. How many years of experience do you have in the construction industry? Please tick [✓] only one box.

☐ 1-2 years ☐ 3-5 years ☐ 6 to 10 years

☐ 11-15 years ☐ over 15 years

2. For how long have you been involved in Lean Construction? Please tick [✓] only one box.

☐ less than 1 year ☐ 1-2 years ☐ 3-5 years

☐ 6-10 years ☐ over 10 years

3. Which of the following best describes your position in the company? Please tick [✓] all applicable options.

☐ Site supervisor ☐ Site manager

☐ Health and safety manager ☐ General foreman

☐ Other, (Please specify):___________________________

4. Please indicate the number of employees in your organisation? Please tick [✓] only one box.

☐ 1-5 ☐ 6-10 ☐ 11-50

☐ 51-250 ☐ 251- 500 ☐ More than 500

5. What size of project does your company mostly engages in? Please tick [✓] only one box.

☐ less than £0.5 million ☐ £0.5- 1million ☐ £1-2million

☐ £2- 5million ☐ More than £5 million

6. Which of the following describes your firm's area/ areas of operation? Please tick [✓] all applicable options.

☐ Building ☐ Commercial

☐Civil engineering ☐ Industrial

☐ Engineering construction ☐ Housing

☐ Other, (Please specify):___________________________ ☐ Infrastructure

Section B:- Features of Lean Construction tools: Potential impact on safety on construction sites

Please use the scale below to answer the following questions by ticking [✓]. The rating scale means:
1= Very bad, 2 = Bad, 3 = Neutral, 4 = Good, 5= Very good.

7. How do the following lean business improvement techniques impact on safety on construction sites?

i.	Workers' empowerment in assignment scheduling	☐1	☐2	☐3	☐4	☐5
ii.	Correlating work methods with workers' skills	☐1	☐2	☐3	☐4	☐5
iii.	Pre-task hazard analysis	☐1	☐2	☐3	☐4	☐5
iv.	Workers involvement in task planning	☐1	☐2	☐3	☐4	☐5
v.	Correlating tasks with workers' ability	☐1	☐2	☐3	☐4	☐5
vi.	Weekly work planning	☐1	☐2	☐3	☐4	☐5
vii.	Supervision planning	☐1	☐2	☐3	☐4	☐5
viii.	Open communication between management and workers	☐1	☐2	☐3	☐4	☐5
ix.	Workers involvement in daily site meetings (DHM)	☐1	☐2	☐3	☐4	☐5
x.	Coordination of workers and simultaneous activities	☐1	☐2	☐3	☐4	☐5
xi.	Process mapping	☐1	☐2	☐3	☐4	☐5
xii.	Critical tasks planning	☐1	☐2	☐3	☐4	☐5
xiii.	Collaborative planning	☐1	☐2	☐3	☐4	☐5
xiv.	Just-in-time	☐1	☐2	☐3	☐4	☐5
xv.	Work methods illustration	☐1	☐2	☐3	☐4	☐5
xvi.	Safety signs and labels	☐1	☐2	☐3	☐4	☐5
xvii.	Visual safety borders and demarcation	☐1	☐2	☐3	☐4	☐5
xviii.	Visibility improvement	☐1	☐2	☐3	☐4	☐5
xix.	Visual inspection	☐1	☐2	☐3	☐4	☐5
xx.	Offsite fabrication	☐1	☐2	☐3	☐4	☐5
xxi.	Equipment failure/Hazards warning and alert systems	☐1	☐2	☐3	☐4	☐5
xxii.	Clean workplace	☐1	☐2	☐3	☐4	☐5
xxiii.	Materials and plants organisation	☐1	☐2	☐3	☐4	☐5
xxiv.	Kanban cards	☐1	☐2	☐3	☐4	☐5
xxv.	Standardisation	☐1	☐2	☐3	☐4	☐5
xxvi.	Integrated supply chain (supplier involvement)	☐1	☐2	☐3	☐4	☐5

Section C: The Impact of Lean business improvement techniques on safety

Please rate the extent of your agreement or your disagreement to answer the following questions by ticking [✓]. The rating scale means:

1 = Strongly disagree, 2 = Disagree, 3 = Neutral, 4 = Agree, 5 = Strongly agree.

8. Workers empowerment in assignment scheduling could reduce accidents caused by time pressure
☐1 ☐2 ☐3 ☐4 ☐5

9. Workers empowerment in assignment scheduling could reduce accidents caused by excessive stress
☐1 ☐2 ☐3 ☐4 ☐5

10. Correlating work methods and workers' skills could reduce accidents caused by poor work methods
☐1 ☐2 ☐3 ☐4 ☐5

11. Correlating work methods and workers' skills could reduce accidents caused by physical and mental inability
☐1 ☐2 ☐3 ☐4 ☐5

12. Workers involvement in work planning could reduce accidents caused by time pressure
☐1 ☐2 ☐3 ☐4 ☐5

13. Workers involvement in work planning could reduce accidents caused by excessive stress
☐1 ☐2 ☐3 ☐4 ☐5

14. Workers involvement in work planning could reduce accidents caused by lack of motivation
☐1 ☐2 ☐3 ☐4 ☐5

15. Correlating tasks with workers' ability could reduce accidents caused by excessive stress
☐1 ☐2 ☐3 ☐4 ☐5

16. Correlating tasks with workers' ability could reduce accidents caused by physical and mental inability
☐1 ☐2 ☐3 ☐4 ☐5

17. Weekly work planning could reduce accidents caused by poor site management
☐1 ☐2 ☐3 ☐4 ☐5

18. Weekly work planning could reduce accidents caused by poor planning and control
☐1 ☐2 ☐3 ☐4 ☐5

19. Weekly work planning could reduce accidents caused by poor coordination of simultaneous activities
☐1 ☐2 ☐3 ☐4 ☐5

20. Supervision planning could reduce accidents caused by poor supervision
☐1 ☐2 ☐3 ☐4 ☐5

21. Supervision planning could reduce accidents caused by poor planning and control
☐1 ☐2 ☐3 ☐4 ☐5

22. Open communication between management and workers could reduce accidents caused by organisational pressure
☐1 ☐2 ☐3 ☐4 ☐5

23. Open communication between management and workers could reduce accidents caused by lack of motivation
☐1 ☐2 ☐3 ☐4 ☐5

1 = Strongly disagree, 2 = Disagree, 3 = Neutral, 4 = Agree, 5 = Strongly agree.

24. Open communication between management and workers could reduce accidents caused by poor communication

☐1 ☐2 ☐3 ☐4 ☐5

25. Coordination of workers and simultaneous activities could reduce accidents caused by site congestion.

☐1 ☐2 ☐3 ☐4 ☐5

26. Coordination of workers and simultaneous activities could reduce accidents caused by poor coordination of simultaneous activities.

☐1 ☐2 ☐3 ☐4 ☐5

27. Daily huddle meetings could be used to improve safety awareness

☐1 ☐2 ☐3 ☐4 ☐5

28. Daily huddle meetings could be used to improve risk management

☐1 ☐2 ☐3 ☐4 ☐5

29. Critical tasks planning could reduce accidents caused by poor planning and control

☐1 ☐2 ☐3 ☐4 ☐5

30. Critical tasks planning could reduce accidents caused by procedural issues

☐1 ☐2 ☐3 ☐4 ☐5

31. Work methods' illustration could reduce accidents caused lack of knowledge

☐1 ☐2 ☐3 ☐4 ☐5

32. Work methods' illustration could reduce accidents caused by procedural issues

☐1 ☐2 ☐3 ☐4 ☐5

33. Safety signs and labels could reduce accidents caused by poor planning and control

☐1 ☐2 ☐3 ☐4 ☐5

34. Safety signs and labels could reduce accidents caused by human error

☐1 ☐2 ☐3 ☐4 ☐5

35. Safety signs and labels could reduce accidents caused by poor communication

☐1 ☐2 ☐3 ☐4 ☐5

36. Safety signs and labels could reduce accidents caused by poorly organised site

☐1 ☐2 ☐3 ☐4 ☐5

37. Safety signs and labels could reduce accidents caused by lack of knowledge

☐1 ☐2 ☐3 ☐4 ☐5

38. Safety signs and labels could reduce accidents caused by unsafe behaviour

☐1 ☐2 ☐3 ☐4 ☐5

39. Visual safety borders and demarcation could reduce accidents caused by human error

☐1 ☐2 ☐3 ☐4 ☐5

40. Visual safety borders and demarcation could reduce accidents caused by poor communication

☐1 ☐2 ☐3 ☐4 ☐5

41. Visual management could be used to reduce trip hazards

☐1 ☐2 ☐3 ☐4 ☐5

1 = Strongly disagree, 2 = Disagree, 3 = Neutral, 4 = Agree, 5 = Strongly agree.

42. Visual inspection could reduce accidents caused by poor supervision
☐1 ☐2 ☐3 ☐4 ☐5

43. Equipment failure/ Hazard warning and alert systems could reduce accidents caused by human error
☐1 ☐2 ☐3 ☐4 ☐5

44. Offsite manufacturing could be used to reduce high risk site activities
☐1 ☐2 ☐3 ☐4 ☐5

45. Offsite manufacturing could be used to reduce site movements
☐1 ☐2 ☐3 ☐4 ☐5

46. Offsite manufacturing could be used to reduce site hazards like noise and dust
☐1 ☐2 ☐3 ☐4 ☐5

47. A clean workplace could reduce accidents caused by site hazards
☐1 ☐2 ☐3 ☐4 ☐5

48. A clean workplace could reduce accidents caused by untidy site
☐1 ☐2 ☐3 ☐4 ☐5

49. A clean workplace could reduce accidents caused by site congestion
☐1 ☐2 ☐3 ☐4 ☐5

50. The organisation of materials and plants could reduce accidents caused by falling objects
☐1 ☐2 ☐3 ☐4 ☐5

51. The organisation of materials and plants could reduce accidents caused by poorly organised site
☐1 ☐2 ☐3 ☐4 ☐5

52. The organisation of materials and plants could reduce accidents caused by untidy site
☐1 ☐2 ☐3 ☐4 ☐5

53. The organisation of materials and plants could reduce accidents caused by site congestion
☐1 ☐2 ☐3 ☐4 ☐5

54. Standardisation enables risk to be thoroughly understood and mitigated.
☐1 ☐2 ☐3 ☐4 ☐5

55. Just-in-time can reduce accidents caused by Site congestion.
☐1 ☐2 ☐3 ☐4 ☐5

56. Collaborative planning could be used to achieve an early identification and management of risks
☐1 ☐2 ☐3 ☐4 ☐5

57. Collaborative planning could be used to achieve better planning of works
☐1 ☐2 ☐3 ☐4 ☐5

58. Collaborative planning raises safety knowledge between contractors
☐1 ☐2 ☐3 ☐4 ☐5

59. Collaborative planning could be used to achieve safer work methods
☐1 ☐2 ☐3 ☐4 ☐5

60. Using Kanban cards makes the site more organised and more productive.
☐1 ☐2 ☐3 ☐4 ☐5

1 = Strongly disagree, 2 = Disagree, 3 = Neutral, 4 = Agree, 5 = Strongly agree.

61. Suppliers involvement collectively enables early identification and management of several risks and safer work methods.

☐1 ☐2 ☐3 ☐4 ☐5

62. Process mapping leads to better planning of works.

☐1 ☐2 ☐3 ☐4 ☐5

Section D: Drivers and Output of applying Lean business improvement techniques in Organisations

63. Please indicate, using the scale below, how important is each of the following factors in driving your organisation to apply Lean Construction:

1 = Little importance, 2 = Some importance, 3 = Quite important, 4 = Important, 5 = Very important.

a. Reduce project cost	☐1	☐2	☐3	☐4	☐5
b. Reduce project duration	☐1	☐2	☐3	☐4	☐5
c. Improve product and services quality	☐1	☐2	☐3	☐4	☐5
d. Improve safety	☐1	☐2	☐3	☐4	☐5
e. Improve productivity	☐1	☐2	☐3	☐4	☐5
f. Improve competitiveness	☐1	☐2	☐3	☐4	☐5
g. Enhance site conditions	☐1	☐2	☐3	☐4	☐5
h. Enhance company image	☐1	☐2	☐3	☐4	☐5
i. Improve presentation	☐1	☐2	☐3	☐4	☐5
j. Improve efficiency	☐1	☐2	☐3	☐4	☐5
k. Deliver value to clients	☐1	☐2	☐3	☐4	☐5
l. Become leading edge	☐1	☐2	☐3	☐4	☐5
m. Increase revenues and profits	☐1	☐2	☐3	☐4	☐5
n. Clients satisfaction	☐1	☐2	☐3	☐4	☐5
o. Economics	☐1	☐2	☐3	☐4	☐5
p. Best practice	☐1	☐2	☐3	☐4	☐5
q. Process improvement	☐1	☐2	☐3	☐4	☐5
r. Make a difference	☐1	☐2	☐3	☐4	☐5
s. Smooth project delivery	☐1	☐2	☐3	☐4	☐5
t. Government reports	☐1	☐2	☐3	☐4	☐5
u. Eliminate wasteful activities	☐1	☐2	☐3	☐4	☐5

64. Please rate the following negative impacts of applying lean techniques, using the scale below, in terms of their level of occurrence in your organisation:
1 = Does not occur, 2 = Little occurrence, 3 = Moderate occurrence, 4 = High occurrence, 5 = Very high occurrence.

a. Excessive stress	☐1	☐2	☐3	☐4	☐5
b. Environmental pollution	☐1	☐2	☐3	☐4	☐5
c. Organisational pressure	☐1	☐2	☐3	☐4	☐5
d. Inadequate resources	☐1	☐2	☐3	☐4	☐5
e. Poor social life	☐1	☐2	☐3	☐4	☐5
f. Difficult to apply	☐1	☐2	☐3	☐4	☐5
g. Time pressure	☐1	☐2	☐3	☐4	☐5

65. Please indicate, using the scale below, how frequent you realise the following outputs in applying lean techniques:
1 = Never, 2 = Seldom, 3 = Often, 4 = Frequent, 5 = Always.

a. Reduce project cost	☐1	☐2	☐3	☐4	☐5
b. Reduce project duration	☐1	☐2	☐3	☐4	☐5
c. Improve product and services quality	☐1	☐2	☐3	☐4	☐5
d. Improve safety	☐1	☐2	☐3	☐4	☐5
e. Improve productivity	☐1	☐2	☐3	☐4	☐5
f. Larger profits for contractors and subcontractors	☐1	☐2	☐3	☐4	☐5
g. Increased accident rate	☐1	☐2	☐3	☐4	☐5
h. Poor human resource management	☐1	☐2	☐3	☐4	☐5
i. Clients' satisfaction	☐1	☐2	☐3	☐4	☐5
j. Greater predictability	☐1	☐2	☐3	☐4	☐5
k. Reduced accidents	☐1	☐2	☐3	☐4	☐5
l. Improved competitiveness	☐1	☐2	☐3	☐4	☐5
m. Increase revenues and profits	☐1	☐2	☐3	☐4	☐5
n. Poor safety	☐1	☐2	☐3	☐4	☐5
o. Improved design	☐1	☐2	☐3	☐4	☐5
p. fewer defects	☐1	☐2	☐3	☐4	☐5
q. Improved cost control	☐1	☐2	☐3	☐4	☐5
r. Improve resources efficiency	☐1	☐2	☐3	☐4	☐5

Section E:- Challenges to application of Lean business improvement techniques in Organisations

66. Please indicate, using the scale below, how much you experience the following challenges in applying Lean techniques in your organisation:
1 = Never, 2 = Seldom, 3 = Often, 4 = Frequent, 5 = Always.

a. High implementation cost	☐1	☐2	☐3	☐4	☐5
b. Non-compliance with instructions	☐1	☐2	☐3	☐4	☐5
c. Lack of Lean knowledge	☐1	☐2	☐3	☐4	☐5
d. Leadership conflict	☐1	☐2	☐3	☐4	☐5
e. Misconceptions about lean	☐1	☐2	☐3	☐4	☐5
f. Complexity	☐1	☐2	☐3	☐4	☐5
g. Lack of cooperation	☐1	☐2	☐3	☐4	☐5
h. Lack of incentives	☐1	☐2	☐3	☐4	☐5
i. Lack of government support	☐1	☐2	☐3	☐4	☐5
j. Change to work approach	☐1	☐2	☐3	☐4	☐5
k. Difficulty to understand	☐1	☐2	☐3	☐4	☐5
l. Unsuitable organisational structure	☐1	☐2	☐3	☐4	☐5
m. Inadequate resources	☐1	☐2	☐3	☐4	☐5

END OF THE QUESTIONNAIRE- THANK YOU FOR YOUR TIME!

Please kindly give your feedback on the Questionnaire by answering the questions below:

1. How long did it take you to complete it? ………………………..
2. Were the instructions clear? ☐ Yes ☐ No
3. Were any of the questions unclear? If so which?

   ……………………………………………………………………….................................

   ……………………………………………………………………………………………….
4. Was the layout of the questionnaire attractive?
5. Any other comments?

   ………………………………………………………………………………………………..

   …………………………………………………………………………………………………

If you would like to receive the research findings, please provide your contact information

Name of respondent:	
Name of company:	
Contact Address:	
Email:	
Telephone:	

Please return the questionnaire using the free post addressed envelope provided

APPENDIX F: TYPICAL INVITATION TO PARTICIPATE IN MAIN SURVEY

TYPICAL COVER LETTER FOR MAIN SURVEY

28th April, 2012

Dear Sir/ Madam,

I am a research student at the School of Technology at the University of Wolverhampton undertaking a Ph.D. research which seeks to investigate the impact of Lean business improvement techniques on safety on construction sites. I would like to invite you to participate in the research. The intended outcome of the research will be a framework that could guide construction organisations in applying Lean business improvement techniques to improve safety on sites. A copy of this will be sent free to all participants. The doctoral research is partially sponsored by the University of Wolverhampton. It is being undertaken under the supervision of Dr Subashini Suresh and Dr David Oloke of the University of Wolverhampton, Professor David Proverbs of the University of the West of England and Dr Rod Gameson of the University of Salford.

A copy of the questionnaire is attached. The purpose of the questionnaire is to obtain your opinion on the safety impacts of Lean business improvement techniques. I will be very grateful if your health and safety manager, project manager, business improvement manager, construction manager and site manager or site supervisor can kindly complete the 5 questionnaires. It is estimated to take approximately 20 minutes to complete. Data obtained from the questionnaire will be treated with strict CONFIDENCE and used for academic purposes only. The completed questionnaire can be kindly returned in the self-addressed FREE POST envelope attached before or by 18th of May 2012.

If you have any questions or queries, please do not hesitate to contact me. Thank you very much in advance for your valuable time and assistance in this research.

Yours faithfully,

Abubakar M. Bashir
Doctoral Researcher
University of Wolverhampton
Mob: 07551284685
Email: abubakar.bashir2@wlv.ac.uk

APPENDIX G: MAIN SURVEY QUESTIONNAIRE

QUESTIONNAIRE ON LEAN BUSINESS IMPROVEMENT TECHNIQUES AND SAFETY

INFORMATION SHEET

Research Title: The Potential Impact of Lean Strategies on Safety on UK Construction Sites

This survey is part of a doctoral research which aims to investigate the potential impact of Lean business improvement techniques on safety. The purpose of the questionnaire is to obtain your opinion on the safety impacts of Lean business improvement techniques.

The questionnaire is in six sections. **Section A** requests information on the respondent and the organisation's profile. **Section B** focuses on impacts of Lean business improvement techniques on safety. **Section C** focuses on the potentiality of the Lean business improvement techniques to reduce accident causations and exposure to risks on construction sites. **Section D** examines the drivers to applying Lean business improvement techniques in organisations. **Section E** examines the challenges in applying Lean business improvement techniques on construction sites. Finally, **Section F** examines the output of applying Lean business improvement techniques on safety.

Please note that participation in this survey is voluntary. Data obtained from the questionnaire will be treated with strict confidence and used for academic purposes only. No records will bear your company's name.

Relying on your broad experience of the industry, please answer all questions. Your contribution in answering these questions would be most appreciated. There are no "correct" or "incorrect" answers. The questionnaire will take approximately 20 minutes to complete.

Please return the completed questionnaire using the addressed free post envelope provided (no stamps required). Should you require or prefer an electronic version of the questionnaire please contact Mr. Abubakar M. Bashir using the information below. Thank you very much for your time.

Abubakar M. Bashir

Doctoral Researcher

School of Technology

University of Wolverhampton

Wulfruna Street

WV1 1LY

Mob: 07551284685

Email: abubakar.bashir2@wlv.ac.uk

Section A:- Profile of Respondent/ Organisation

1. How many years of experience do you have in the construction industry? Please tick [✓] only one box.

☐ 0-2 years ☐ 3-5 years ☐ 6 to 10 years

☐ 11-15 years ☐ over 15 years

2. Which of the following best describes your position in the company? Please tick [✓] only one box.

☐ Project manager ☐ Site manager

☐ Health and safety manager ☐ Site supervisor

☐ Other, (Please specify):___________________________

3. Please indicate the number of employees in your company? Please tick [✓] only one box.

☐ 1-5 ☐ 6-10 ☐ 11-50

☐ 51-250 ☐ More than 250

4. What value of project does your company mostly engages in? Please tick [✓] only one box.

☐ less than £0.5 million ☐ £0.5- 1million ☐ £1.1-2million

☐ £2.1- 5million ☐ More than £5 million

Section B: Impact of Lean business improvement techniques on safety on construction sites

Please use the scale below to answer the following questions by ticking [✓]. The rating scale means:

1= Very negative, 2 = Negative, 3 = Neutral, 4 = Positive, 5= Very positive

1. How do the following lean business improvement techniques impact on safety on construction sites?

i.	Workers' empowerment in assignment scheduling	☐1	☐2	☐3	☐4	☐5
ii.	Correlating work methods with workers' skills	☐1	☐2	☐3	☐4	☐5
iii.	Pre-task hazard analysis	☐1	☐2	☐3	☐4	☐5
iv.	Workers involvement in task planning	☐1	☐2	☐3	☐4	☐5
v.	Correlating tasks with workers' ability	☐1	☐2	☐3	☐4	☐5
vi.	Weekly work planning	☐1	☐2	☐3	☐4	☐5
vii.	Open communication between management and workers	☐1	☐2	☐3	☐4	☐5
viii.	Workers involvement in daily huddle meetings (DHM)	☐1	☐2	☐3	☐4	☐5
ix.	Coordination of workers and simultaneous activities	☐1	☐2	☐3	☐4	☐5
x.	Process mapping	☐1	☐2	☐3	☐4	☐5
xi.	Critical tasks planning	☐1	☐2	☐3	☐4	☐5
xii.	Collaborative planning	☐1	☐2	☐3	☐4	☐5
xiii.	Just-in-time	☐1	☐2	☐3	☐4	☐5
xiv.	Work methods illustration	☐1	☐2	☐3	☐4	☐5
xv.	Safety signs and labels	☐1	☐2	☐3	☐4	☐5
xvi.	Visual safety borders and demarcation	☐1	☐2	☐3	☐4	☐5
xvii.	Visibility improvement	☐1	☐2	☐3	☐4	☐5
xviii.	Visual inspection	☐1	☐2	☐3	☐4	☐5
xix.	Offsite fabrication	☐1	☐2	☐3	☐4	☐5
xx.	Equipment failure/Hazards warning and alert systems	☐1	☐2	☐3	☐4	☐5
xxi.	Clean workplace	☐1	☐2	☐3	☐4	☐5
xxii.	Materials and plants organisation	☐1	☐2	☐3	☐4	☐5
xxiii.	Standardisation	☐1	☐2	☐3	☐4	☐5
xxiv.	Integrated supply chain (supplier involvement)	☐1	☐2	☐3	☐4	☐5

Section C: The Potential Impact of Lean business improvement techniques on reducing accident causations

Please rate the extent of your agreement or your disagreement to answer the following questions by ticking [✓]. The rating scale means:

1 = Strongly disagree, 2 = Disagree, 3 = Neutral, 4 = Agree, 5 = Strongly agree.

WORKERS RELATED TECHNIQUES (i.e. techniques related to handling the site operatives)

1. Workers empowerment in assignment scheduling could reduce accidents caused by time pressure
☐1 ☐2 ☐3 ☐4 ☐5

2. Correlating work methods with workers' ability could reduce accidents caused by excessive stress
☐1 ☐2 ☐3 ☐4 ☐5

3. Correlating work methods with workers' ability could reduce accidents caused by physical and mental inability
☐1 ☐2 ☐3 ☐4 ☐5

4. Workers empowerment in assignment scheduling could reduce accidents caused by excessive stress
☐1 ☐2 ☐3 ☐4 ☐5

5. Workers involvement in work planning could reduce accidents caused by lack of motivation
☐1 ☐2 ☐3 ☐4 ☐5

6. Coordination of workers and simultaneous activities could reduce accidents caused by site congestion.
☐1 ☐2 ☐3 ☐4 ☐5

PLANNING RELATED TECHNIQUES (i.e. techniques related to planning activities on the site)

1. Weekly work planning could reduce accidents caused by poor site management
☐1 ☐2 ☐3 ☐4 ☐5

2. Weekly work planning could reduce accidents caused by poor planning and control
☐1 ☐2 ☐3 ☐4 ☐5

3. Collaborative planning could be used to achieve an early identification and management of risks
☐1 ☐2 ☐3 ☐4 ☐5

4. Collaborative planning could be used to achieve better planning of works
☐1 ☐2 ☐3 ☐4 ☐5

5. Collaborative planning raises safety knowledge between contractors
☐1 ☐2 ☐3 ☐4 ☐5

6. Collaborative planning could be used to achieve safer work methods
☐1 ☐2 ☐3 ☐4 ☐5

7. Critical tasks planning could reduce accidents caused by poor planning and control
☐1 ☐2 ☐3 ☐4 ☐5

Please rate the extent of your agreement or your disagreement to answer the following questions by ticking [✓]. The rating scale means:

1 = Strongly disagree, 2 = Disagree, 3 = Neutral, 4 = Agree, 5 = Strongly agree.

TASKS RELATED TECHNIQUES (i.e. techniques related to the site operations)

1. Work methods' illustration could reduce accidents caused lack of knowledge
☐1 ☐2 ☐3 ☐4 ☐5

2. Work methods' illustration could reduce accidents caused by procedural issues
☐1 ☐2 ☐3 ☐4 ☐5

3. Offsite manufacturing could be used to reduce high risk site activities
☐1 ☐2 ☐3 ☐4 ☐5

4. Offsite manufacturing could be used to reduce site hazards like noise and dust
☐1 ☐2 ☐3 ☐4 ☐5

5. Pre-task hazard analysis could help in risk identification and reduction
☐1 ☐2 ☐3 ☐4 ☐5

WORKPLACE RELATED TECHNIQUES (i.e. techniques related to the site/ working environment)

1. A clean workplace could reduce accidents caused by site hazards
☐1 ☐2 ☐3 ☐4 ☐5

2. A clean workplace could reduce accidents caused by untidy site
☐1 ☐2 ☐3 ☐4 ☐5

3. A clean workplace could reduce accidents caused by site congestion
☐1 ☐2 ☐3 ☐4 ☐5

4. The organisation of materials and plants could reduce accidents caused by falling objects
☐1 ☐2 ☐3 ☐4 ☐5

5. The organisation of materials and plants could reduce accidents caused by site congestion
☐1 ☐2 ☐3 ☐4 ☐5

COMMUNICATION RELATED TECHNIQUES (i.e. techniques related to exchanging information and ideas on site)

1. Open communication between management and workers could reduce accidents caused by organisational pressure
☐1 ☐2 ☐3 ☐4 ☐5

2. Daily huddle meetings could reduce accidents caused by poor communication
☐1 ☐2 ☐3 ☐4 ☐5

3. Daily huddle meetings could be used to improve safety awareness
☐1 ☐2 ☐3 ☐4 ☐5

4. Daily huddle meetings could be used to improve risk management
☐1 ☐2 ☐3 ☐4 ☐5

Please rate the extent of your agreement or your disagreement to answer the following questions by ticking [✓]. The rating scale means:

1 = Strongly disagree, 2 = Disagree, 3 = Neutral, 4 = Agree, 5 = Strongly agree.

VISUAL MANAGEMENT TECHNIQUES (i.e. techniques related to improving visibility on site)

1. Safety signs and labels could reduce accidents caused by human error
☐1 ☐2 ☐3 ☐4 ☐5

2. Safety signs and labels could reduce accidents caused by poor communication
☐1 ☐2 ☐3 ☐4 ☐5

3. Safety signs and labels could reduce accidents caused by unsafe behaviour
☐1 ☐2 ☐3 ☐4 ☐5

4. Safety signs and labels could reduce accidents caused by untidy site.
☐1 ☐2 ☐3 ☐4 ☐5

5. Visual safety borders and demarcation could reduce accidents caused by human error
☐1 ☐2 ☐3 ☐4 ☐5

6. Visibility improvement could be used to reduce trip hazards
☐1 ☐2 ☐3 ☐4 ☐5

7. Visibility improvement could reduce accidents caused by human error
☐1 ☐2 ☐3 ☐4 ☐5

OTHER LEAN BUSINESS IMPROVEMENT TECHNIQUES

1. Visual inspection could reduce accidents caused by poor supervision
☐1 ☐2 ☐3 ☐4 ☐5

2. Standardisation enables risk to be thoroughly understood and mitigated.
☐1 ☐2 ☐3 ☐4 ☐5

3. Just-in-time can reduce accidents caused by Site congestion.
☐1 ☐2 ☐3 ☐4 ☐5

4. Suppliers involvement collectively enables early identification and management of several risks.
☐1 ☐2 ☐3 ☐4 ☐5

5. Suppliers involvement collectively enables selection of safer work methods.
☐1 ☐2 ☐3 ☐4 ☐5

6. Process mapping leads to better planning of works.
☐1 ☐2 ☐3 ☐4 ☐5

Section D: Drivers to applying Lean business improvement techniques in your Organisation

Please indicate, using the scale below, how important is each of the following factors in driving your organisation to apply Lean Construction:

1 = Little importance, 2 = Some importance, 3 = Quite important, 4 = Important, 5 = Very important.

a. Reduce project cost	☐1	☐2	☐3	☐4	☐5
b. Reduce project duration	☐1	☐2	☐3	☐4	☐5
c. Improve product and services quality	☐1	☐2	☐3	☐4	☐5
d. Improve safety	☐1	☐2	☐3	☐4	☐5
e. Improve productivity	☐1	☐2	☐3	☐4	☐5
f. Improve competitiveness	☐1	☐2	☐3	☐4	☐5
g. Enhance company image	☐1	☐2	☐3	☐4	☐5
h. Improve presentation of products and services	☐1	☐2	☐3	☐4	☐5
i. Improve efficiency	☐1	☐2	☐3	☐4	☐5
j. Deliver value to clients	☐1	☐2	☐3	☐4	☐5
k. Become leading edge in practice	☐1	☐2	☐3	☐4	☐5
l. Increase revenues and profits	☐1	☐2	☐3	☐4	☐5
m. Economise resources	☐1	☐2	☐3	☐4	☐5
n. Best practice	☐1	☐2	☐3	☐4	☐5
o. Government reports	☐1	☐2	☐3	☐4	☐5
p. Eliminate wasteful activities	☐1	☐2	☐3	☐4	☐5

Section E:- Challenges to application of Lean business improvement techniques in your Organisation

1. Please indicate, using the scale below, how much you experience the following challenges in applying Lean techniques in your organisation:

1 = Never, 2 = Seldom, 3 = Often, 4 = Frequent, 5 = Always.

a. High implementation cost	☐1	☐2	☐3	☐4	☐5
b. Non-ccompliance with instructions	☐1	☐2	☐3	☐4	☐5
c. Lack of Lean knowledge	☐1	☐2	☐3	☐4	☐5
d. Misconceptions about lean	☐1	☐2	☐3	☐4	☐5
e. Complexity	☐1	☐2	☐3	☐4	☐5
f. Lack of cooperation	☐1	☐2	☐3	☐4	☐5
g. Lack of incentives	☐1	☐2	☐3	☐4	☐5
h. Lack of government support	☐1	☐2	☐3	☐4	☐5
i. Change to work approach	☐1	☐2	☐3	☐4	☐5

j. Difficulty to understand ☐1 ☐2 ☐3 ☐4 ☐5

k. Unsuitable organisational structure ☐1 ☐2 ☐3 ☐4 ☐5

l. Inadequate resources ☐1 ☐2 ☐3 ☐4 ☐5

Section F:- Outcomes of applying Lean business improvement techniques in your Organisation

1. Please indicate, using the scale below, how frequent you achieve the following outcomes in applying lean techniques:
1 = Never, 2 = Seldom, 3 = Often, 4 = Frequent, 5 = Always.

a. Reduce project cost ☐1 ☐2 ☐3 ☐4 ☐5

b. Reduce project duration ☐1 ☐2 ☐3 ☐4 ☐5

c. Improve product and services quality ☐1 ☐2 ☐3 ☐4 ☐5

d. Improve safety ☐1 ☐2 ☐3 ☐4 ☐5

e. Improve productivity ☐1 ☐2 ☐3 ☐4 ☐5

f. Larger profits ☐1 ☐2 ☐3 ☐4 ☐5

g. Poor human resource management ☐1 ☐2 ☐3 ☐4 ☐5

h. Clients' satisfaction ☐1 ☐2 ☐3 ☐4 ☐5

i. Greater predictability ☐1 ☐2 ☐3 ☐4 ☐5

j. Improved competitiveness ☐1 ☐2 ☐3 ☐4 ☐5

k. Increase revenues and profits ☐1 ☐2 ☐3 ☐4 ☐5

l. Poor safety ☐1 ☐2 ☐3 ☐4 ☐5

m. Improve resources efficiency ☐1 ☐2 ☐3 ☐4 ☐5

END OF THE QUESTIONNAIRE- THANK YOU FOR YOUR TIME!

If you would like to receive the research outcome, please provide your contact information

Name of respondent:	
Name of company:	
Contact Address:	
Email:	
Telephone:	

Please return the questionnaire using the free post addressed envelope provided

APPENDIX H: VALIDATION INTERVIEW ON RESEARCH FINDINGS AND OUTCOME

Please provide comments on how valid the research findings are with regards to your experience by checking [] one of the multiple choice options and also by providing your comments where appropriate.

Section A: Background of Respondent

General Information

Please indicate your position in the company ……………………………………………………………………………………………

How many years of experience do you have in the construction industry ……………………………………………………………………………………………

For how long have you been practicing Lean Construction ……………………………………………………………………………………………

Section B: Impact of Lean Construction Techniques in Promoting Safety

1. The research found that the Lean techniques labelled L3,…, L10 on the framework could be used to address workers related safety issues identified in the framework. From your industry experience, how valid is this finding?

Yes, highly valid [ ]
Yes, valid [ ]
No, not valid [ ]
Not sure [ ]

Please provide any additional comments:

2. The research found that the Lean techniques labelled L12,…, L14 on the framework could be used to address environment related safety issues identified in the framework. From your industry experience, how valid is this finding?

Yes, highly valid [ ]
Yes, valid [ ]
No, not valid [ ]
Not sure [ ]

Please provide any additional comments:

3. The research found that the Lean techniques labelled L5,…, L13 could be used to address management related safety issues identified in the framework. From your industry experience, how valid is this finding?

Yes, highly valid [ ]
Yes, valid [ ]
No, not valid [ ]
Not sure [ ]

Please provide any additional comments:

4. The research found that the Lean techniques labelled L1,…, L22 could be used to address task related safety issues identified in the framework. From your industry experience, how valid is this finding?

Yes, highly valid ☐
Yes, valid ☐
No, not valid ☐
Not sure ☐

Please provide any additional comments:

Section C: Framework for using LC techniques to promote safety

The research findings have been consolidated in the form of a framework to guide contracting organisations in selecting and adopting suitable Lean Construction techniques to address corresponding safety issues in order to promote Safety on construction sites at the planning stage. You are kindly requested to provide some feedback on the framework by answering the following questions.

5. The research found that Lean Construction techniques could be used to promote safety on construction sites using the attached framework. To what extent do you agree with this finding?

Strongly agree ☐
Agree ☐
Not sure ☐
Disagree ☐

Please provide any additional comments on the validity of the framework:

Challenges to applying Lean Construction Techniques
The study identified the following as the challenges facing Lean Construction practice in the UK contracting organisations: Changing employees' working culture Cost of implementation Lack of Lean knowledge Long implementation time Complexity Lack of cooperation from employees Lack of incentives Lack of long term forecast and investment Low effort to learn Misconceptions about Lean High expectations from management 7. In your opinion, do you agree that the list above exhaust all the challenges? Yes ☐ No ☐ If No, in your opinion, please specify other challenges facing Lean Construction practice
Strategies that could be used to overcome the challenges
The interviews identified the following as strategies that could be used to overcome the challenges facing Lean Construction practice: Enlightenment on benefits of lean and need for change Publication of results Reduce the fear/ reservations Education Get clients to insist on lean application Workers involvement and empowerment Top management involvement and support Persistence Total belief by site team and supply chain Government policies and legislation Simplify the language of Lean Robust planning Gradual step-by-step implementation

8. In your opinion, do you agree that the list above exhaust all the strategies?
Yes ☐
No ☐

If No, in your opinion, please specify other strategies that could be used to overcome the challenges

Thank you very much for your time